4. Mechanistic Design

4.1. Introduction

This chapter provides a complete discussion of the mechanistic design method. The AKFPD mechanistic method is approved for designing all types of asphalt concrete pavement structures. Chapter 2 provides detailed information concerning appropriate applications for this design method.

There are many systems for mechanistically designing a flexible pavement structure. Although some Alaska researchers may have at least passing familiarity with a wide range of mechanistic design technologies, most of these methods have never been used for designing pavements in Alaska. The following presentation covers only the mechanistic methods the DOT&PF has adopted for use and associated underlying principles.

4.2. Summary of Mechanistic Design

In 1976, DOT&PF began a comprehensive research effort to improve its method for designing flexible pavement structures. That same year, the International Pavement Design Conference at the University of Michigan, Ann Arbor, introduced several computer programs for doing mechanistic pavement design. It appeared that mechanistic design methods might offer great potential for application in Alaska. However, the computer programs were considered to be research-level design tools at the time, and the expertise for installing and running them was not readily available. Furthermore, mechanistic design programs required mainframe computer resources—these were the days before powerful personal computers were available.

Most of the research thrust between 1976 and 1982 was toward developing an empirical method of design based on data collected from Alaska roadway sections. This line of research was successful in producing the excess fines method of pavement design in 1982. During this same period, though, interest continued to grow in the area of mechanistic design. By 1983, several mechanistic design programs had been collected and installed for DOT&PF access on the Boeing computer system in Seattle, Washington. This work was done as part of a DOT&PF research project that also produced the first DOT&PF guide for mechanistic pavement design.[8] DOT&PF mechanistic design classes have continually used *Use of Layered Theory in the Design and Evaluation of Pavement Systems*.

Mechanistic methods were introduced to the general DOT&PF community in 1983. Until the late 1980s, mechanistic methods were used mostly for research work, and highway pavement designs were nearly always handled using the excess fines method. During the period 1988 to 1990, the AKOD (Alaska Overlay Design) program was developed.[9] The AKOD program combined all of the separate computational steps required by the mechanistic design process into a few easily used input and output screens. AKOD gave mechanistic design capability to all DOT&PF engineers. Development of the AKOD program continued through the 1998 revision (AKOD98). A new program was developed as the mechanistic design component of AKFPD. The new program is an updated, highly modified derivative of the AKOD concept.

The heart of the mechanistic design method is the difficult calculation of stresses and strains, i.e., structural response, at selected locations within the pavement structural layers. Hicks[8] discussed several programs useful for performing these calculations and selected one of these, ELSYM5, as the stress/strain computational subroutine in AKOD. ELSYM5 has also been incorporated into AKFPD to perform this same function.

In addition to references previously cited regarding mechanistic design, textbooks by Yoder and Witczak,[10] Ullidtz,[11, 12] and Huang[13] provide an excellent broad base of information.

4.3. Design Principles

Alaska's mechanistic design method relies on the following three principles:

1. The pavement structure is amenable to structural analysis as a basic mechanical system of elastic layers, i.e., the structural response of the system can be calculated if the loads and the physical properties of the system's layers are known. In the Alaska mechanistic method, structural response is calculated in terms of stresses and strains at specific critical locations within the layered pavement structure (the computer program module ELSYM5 is used for this purpose).

2. Structural response at critical locations in the pavement structure is functionally related to pavement performance. Using this principle, it is possible to plug stress and strain values (calculated by ESYM5) into simple, empirical equations and thereby calculate the number of design load repetitions that will cause the structure to fail (requires application of empirically derived damage equations).

   Damage = f (σ, ε, loads)

3. Pavement failure is the end result of a linear, incremental mechanical process. Pavement structural failure can therefore be modeled using Miner's law—a method of predicting failure by summing up fractional increments of damage.

$$\sum_{i=1}^{i=total} \left(N_a / N_f \right)_i \geq 1 \text{ (a definition of failure)}$$

4.3.1. Calculating Stresses and Strains

The first computational step in Alaska's mechanistic design process is determining stresses and strains, i.e., structural response, at selected locations within the pavement structural layers using layered system analysis. In his 1983 publication,[8] Hicks discussed several programs useful for analyzing elastic layered systems, and he selected one of these, ELSYM5, as the stress/strain computational subroutine for use in AKOD. Nearly 20 years later, ELSYM5 has been incorporated into AKFPD to perform this same important computational function.

In simplest terms, the engineer supplies ELSYM5 with input values of thickness and strength (modulus and Poisson's ratio) for each layer. Input also includes vehicle load configuration and magnitude. Then, ELSYM5 calculates stresses and strains at any location within the pavement structure selected by the designer. Figure 4-1 shows a pavement structure defined in terms of individual elastic layers.

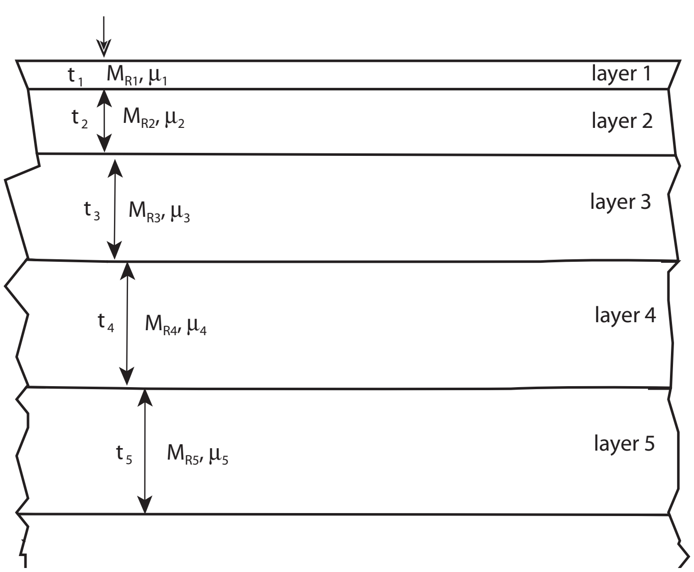


Figure 4-1. Typical Pavement Structure Showing Elastic Layers

The mathematical and programming details of how ELSYM5 performs these calculations are far beyond the scope of this manual. However, it is important to understand the general nature of the function performed by ELSYM5 as well as the principles and assumptions underlying ELSYM5's stress and strain calculations.

Hicks covered this subject quite well in Chapter 2 of his 1983 publication.[8] For analyzing layered pavement systems, he wrote: "Procedures for prediction of traffic induced deflections, stresses and strains in pavement systems are based on the principle of continuum mechanics. The essential factors that must be considered in predicting the response of layered pavement systems are: (1) the stress-strain behavior of the materials; (2) the initial and boundary conditions of the problem; and (3) the partial differential equations which govern the problem. The highway engineer, however, need only concern himself with the stress-strain behavior of the material, the physical configuration of the problem, and the general assumptions that have been made or implied in developing solutions to the layered system problem." In the Alaska mechanistic method, the "solution to the layered system problem" is ELSYM5.

ELSYM5 was selected for use in the AKFPD program because its theoretical basis and operational characteristics (within the personal computer environment) are suited to handling Alaska pavement designs. With ELSYM5, or any other layered system solution, you must use realistic input values and must understand the assumptions and limitations used in developing the solution.

Hicks identified assumptions used in developing elastic layered system solutions such as ELSYM5.

Assumptions applicable to all elastic layer solutions:

- Each layer is infinite in horizontal extent and is composed of isotropic, homogeneous, linearly elastic material.
- Surface loadings can be represented as circular areas of uniform stress.
- Interface conditions between layers can be designated as either perfectly rough (called the "continuous" or "full friction" condition) or perfectly smooth (called the "no friction" or "slippery" condition).
- The underlying layer continuously supports the layer above.
- Inertial forces and vibrations are considered small in the elastic system and can be disregarded. Vibrations can damage the pavement by densifying granular materials and causing rutting, but this effect is not accounted for in mechanistic design.
- Deformations in the elastic system are small and can be disregarded.
- Temperature variations do not affect the elastic layered system.

Assumptions and limitations specific to ELSYM5:

- All loads are identical, uniform, and circular.
- All loads are placed at the surface of the elastic system and oriented normal to that surface.
- A pavement structure of up to five layers can be analyzed.
- The surface of the top layer is free of shear stresses.
- Interfaces between layers are continuous, i.e., full friction.
- Nonlinear elastic behavior of materials—stress sensitivity—cannot be accommodated in ELSYM5 (see discussion below).

- The pavement structure modeled by ELSYM5 is an axisymmetric solid, which means that both load and pavement geometrics are symmetrical about a common centerline. Because of this axisymmetry, ELSYM5 cannot be used to analyze the effects of loads applied near the pavement edge, near cracks, or other edge-type boundaries.

ELSYM5 input requirements:

- One or more wheel loads must be specified at designer-selected locations at the surface of the pavement structure. A maximum of eight identical loads can be used (see limitations listed above). The solution uses the principles of superposition to solve for stresses and strains due to application of multiple wheel loads. This means that ELSYM5 first calculates the stresses and strains caused by each load independently. Then, by applying superposition, total stresses and strains at any point in the elastic layer system are determined as the sum of stress and strain contributions from each load for that point.

  Chapter 6 contains information about vehicle loadings that the engineer can use for designing pavements.

- The thickness must be defined for each layer of the pavement structure. Each layer except the bottom one is assigned a finite thickness. The bottom elastic layer can be given a finite thickness or defined as having semi-infinite thickness (a "bottomless" layer). If you assign a finite thickness to the bottom layer, the program automatically assumes that the base of the bottom layer is rigidly supported. In this case the program also assumes that the interface between the base of the bottom layer and the rigid support is continuous.

- Each layer of the pavement must be assigned two elastic properties.

  1. Resilient modulus M_R (sometimes called the repeated-load or "dynamic" elastic modulus)

     $M_R = \sigma_d / \varepsilon_r$ Where:

     σ_d = repeated axial stress (psi)

     ε_r = recoverable elastic (resilient) strain

     The repeated axial stress (σ_d) is defined as a repeated series of pulse loadings, where each load pulse is followed by a short rest period. One cycle of the pulsed load/rest series usually consists of a load pulse lasting 0.1 second followed by a rest period of 0.9 second.

     The recoverable elastic strain (ε_r) is defined as that portion of strain, due to σ_d, that is completely recovered when the load is released. For all materials that are not perfectly elastic, a portion of the load-induced strain will be nonrecoverable. This nonrecovery phenomenon is due to plastic deformation or some other form of permanent displacement.

  2. Poisson's ratio

     $\mu = \varepsilon_{lateral} / \varepsilon_{load\ axis}$ Where:

     $\varepsilon_{lateral}$ = lateral strain (normal to the axial load direction) caused by application of the axial load

     $\varepsilon_{load\ axis}$ = axial strain (parallel to the axial load direction) caused by application of the axial load

Chapter 5 provides specific information about appropriate modulus and Poisson's ratio values that the engineer can use for designing pavements. M_R should not be confused with another measure of dynamic elastic modulus known as the complex modulus (E*). E* is not presently used in DOT&PF mechanistic design methodology.

Some materials degrade when crushed and handled. **It is important that the M_R value used as design input truly represents the strength of the material after it has been placed and compacted.** If the degradation value (Alaska Test Method T-13) of the material is less than 45, check with the regional materials engineer for guidance.

You must define the locations where ELSYM5 will calculate stresses and strains within the layered elastic system.

ELSYM5 output used in Alaska's mechanistic design method:

ELSYM5 will determine the stress/strain response at any location within a specified elastic layered system due to a specified load. In fact, ELSYM5 produces more output values than are actually used in Alaska's mechanistic design method. You must know which ELSYM5 output values to use and where (within the layered structure) ELSYM5 must calculate these values. Only two of values produced by ELSYM5 are used in Alaska's method, and the locations that must be selected for analysis are very specific.

The two output values of interest are:

1. Maximum horizontal tensile strain, ε_t, at the bottom of specified layers
2. Maximum vertical compressive stress, σ_v, at the top of specified layers

The following section describes, in detail, which layers are specified for evaluation according to strain and which are evaluated according to stress, and why.

A few more words are necessary about selecting ELSYM5 analysis locations. As has been stated above, you will specify calculation of stresses and strains either at the top or the bottom of specified layers. But where (in a horizontal sense) along the top or the bottom of a layer will the **maximum** stress or strain value be found? The wheel configuration of the design load (wheel locations) determines where maximum stresses or strains will be found. In the simplest case of a single wheel design load, the maximum value will be found directly under the center of the load. For design load configurations having two or more wheels, various locations along the bottom of the layer must be searched to find the maximum value. It is important to realize that, because of superposition effects, the horizontal location where the maximum value will be found will change as the depth of the analysis increases. Comparison of Figure 4-2 and 4-3 provides a visual, conceptual example of how superposition applies to a layered pavement structure. Figure 4-2 shows how the load of single wheel is distributed with depth. For example, the load-induced vertical compression stress "felt" by the soil at 36 inches depth would be much less than the stress at the pavement surface directly beneath the tire. Figure 4-3 shows how the depth-distributed loads from two tires superimpose (and add together) at some depth. In Figure 4-3, see how the load distributions of the two tires overlap between the tires. When multiwheel design loads are involved, it is often possible to simplify the search for the maximum horizontal strain value at the bottom of heavily bound layers. Figure 4-4 indicates how analysis locations are selected, and how taking advantage of the symmetry of multiwheel configurations can minimize the number of search locations.

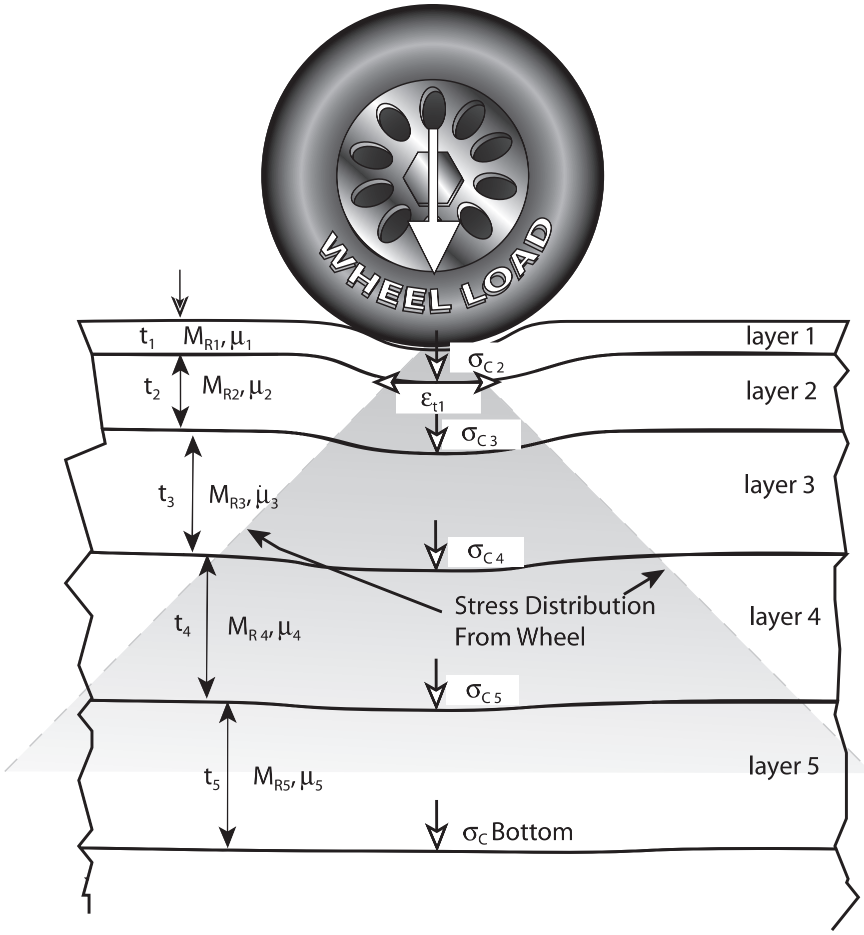


Figure 4-2. Elastic Pavement Layers Undergoing Simple Loading

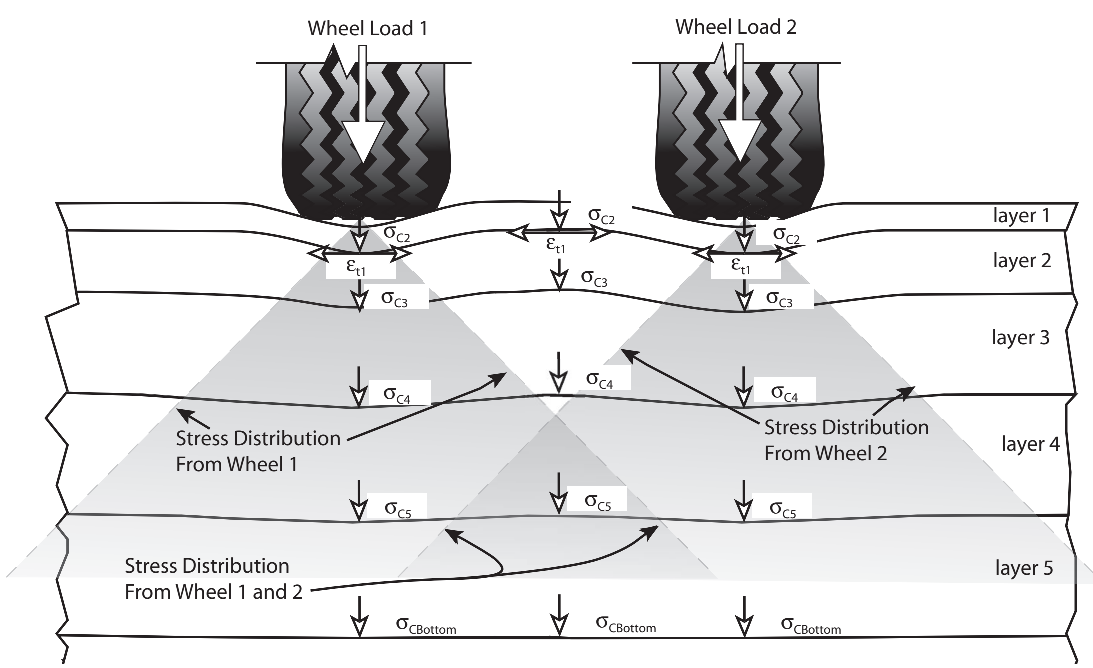


Figure 4-3. Elastic Pavement Layers Illustrating Superposition Effect

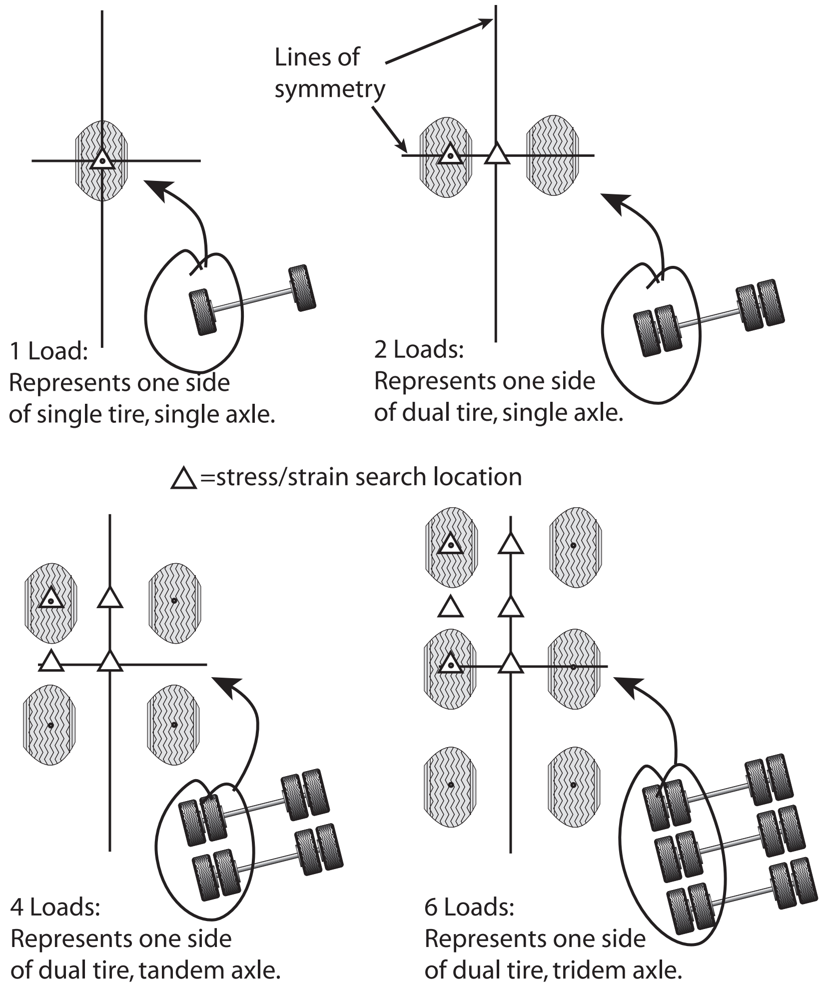


Figure 4-4. Plan View of Design Loads With Structural Response Search Locations Shown

4.3.2. Relating Structural Response to Performance (Estimating the Number of Load Repetitions to Failure)

Empirical equations have been developed that relate stresses and strains at specific locations within the pavement structure to the number of design load repetitions that will cause the structure to fail. These equations are variously known as "damage equations" or "transfer functions." From many such equations found in the literature, DOT&PF has selected two equations for application in the Alaska mechanistic design method. These equations have been incorporated into the AKFPD program and are discussed below.

Why two damage equations used instead of just one? The answer is that the Alaska mechanistic design method defines two distinctly different modes of pavement structural failure. Each mode of failure is controlled by a different structural response parameter.

Fatigue Failure: This type of failure exhibits itself as fatigue cracks (alligator cracks) that are seen at the pavement surface. Only heavily bound layers such as the asphalt concrete surfacing and heavily bound bases are susceptible to this failure mode. Fatigue cracking originates at the bottom of the bound layer and propagates upward to the surface. All heavily bound layers will become fatigue cracked after they are subjected to enough load repetitions. Fatigue failure of heavily bound layers is analogous to a paper clip failing after it is bent many times. Figure 4-5 is a photograph showing advanced alligator cracking.

Figure 4-5. Advanced Alligator Cracking of Highway Pavement

The Asphalt Institute (TAI) developed an equation that predicts, for each heavily asphalt-bound layer, the number of load repetitions until fatigue failure (bottom-up cracking failure) occurs. The TAI equation applies only to heavily bound layers where asphalt cement has been used as the binder. The TAI equation may not be fully accurate if polymer-modified asphalt cements are used or if the asphalt concrete is not representative of standard hot mix materials, e.g., stone mastic asphalt (SMA). However, until an improved method is developed, the TAI equation provides adequate results. The response parameter used in the TAI equation for each layer is the maximum horizontal tensile strain (ε_h) at the bottom of that layer.

Functional Failure: This mode of failure appears as a combination of roughness and rutting (sometimes called functional distress). Failure occurs after the pavement structure is subjected to enough load repetitions to cause permanent deformations of unbound or lightly bound lower layers. All layers that are not heavily bound and susceptible to fatigue failure are susceptible to functional failure.

The Per Ullidtz equation predicts, for each unbound or lightly bound layer, the number of load repetitions until functional failure of that layer occurs. The response parameter used in the Per Ullidtz equation is the vertical compressive stress (σ_v) at the top of unbound or very lightly bound layers.

The TAI equation—for fatigue failure (applicable to asphalt concrete and other heavily bound layers) is:

$$N_f = C \times 0.07958 \times \varepsilon_h^{-3.291} \times \left|E^*\right|^{-0.854}$$

(for fatigue cracking over 45% of the wheel path area equivalent to about 20% cracking of the total area)

$$C = 10^M$$

$$M = 4.84 \times \left(\frac{V_b}{V_v + V_b} - 0.69 \right)$$

where:

N_f = fatigue life (number of design load repetitions to fatigue failure)

ε_h = maximum horizontal tensile strain at the bottom of the bound layer, $^{in}\!/_{in}$

$\left|E^*\right|$ = dynamic modulus of the asphalt concrete material, psi

(use M_R value for asphalt concrete)

V_v = percent air voids volume in total mix

V_b = percent binder volume

where:

$$V_b = \frac{\gamma_{mix} \cdot \%AC}{G_b \cdot \gamma_W}$$

where:

γ_{mix} = mix density, pcf

% AC = binder content, weight %

G_b = binder specific gravity

γ_W = water density, pcf (62.4 pcf)

The Per Ullidtz equation—for functional failure (applicable to unbound or lightly bound layers) is:

$$N_f = \frac{1}{R} \times 3.069\,x10^{10} \times \left(\frac{E}{E_0} \right)^{3.26\,b} \times \sigma_v^{-3.26}$$

(for about 1-inch rut depth)

where:

N_f = number of design load repetitions to functional failure

R = regional factor = 2.75 for Alaska conditions

E = dynamic modulus of the unbound or lightly bound material, psi

E_0 = 23, 000 psi

$b = 1.16$ if $E < E_0$; otherwise $b = 1$

σ_v = maximum vertical compressive stress at the top of the layer, psi

Keep in mind where the horizontal tensile strain ε_h and vertical compressive stress σ_v values used in the above equations come from; they are calculated by the ELSYM5 module of the AKFPD program.

N_f values calculated using the above equations define the maximum number of design-load repetitions (the allowable repetitions) that can be applied to the pavement structure before it fails. In other words, these equations define the potential "life" of the pavement structure in terms of load repetitions to failure (N_f). It should be obvious that any number of load repetitions < N_f will consume a fraction of that life. Similarly, load repetitions ≥ N_f will destroy the pavement structure. Conceptually, the fractional portion of the pavement structure's life consumed by a total number of applied loads (N_a) can be calculated simply by dividing the number of applied loads by the allowable repetitions to failure (N_a/N_f). Failure is said to occur when $N_a/N_f \geq 1$. This line of reasoning leads to discussion of the next principle.

4.3.3 Predicting Structural Failure by Summing up Damage Increments

Mechanistic design applies the incremental damage concept through the use of Miner's law.

The $N_a/N_f \geq 1$ equation introduced above is conceptual. The equation is used in a modified form in the actual pavement design process. The modified equation (known as Miner's law) expresses failure as an incremental process that is calculated using simple summation. In Miner's law, a failed condition is approached as fractional increments of damage are added together. Each increment can be thought of as a fraction of total failure caused by design load repetitions applied when a specific combination load and/or materials conditions exist (such as during different seasons of the year).

The Miner's law expression presented below shows that a condition of failure exists when the sum of damage increments exceeds 1.

$$\sum_{i=1}^{i=total} \left({N_a}/{N_f} \right)_i \geq 1$$

where:

N_a = the actual number of design vehicle loads applied during the ith set of conditions

N_f = the number of design loads that would cause failure during the ith set of conditions

The $\left({N_a}/{N_f} \right)_i$ term represents the fractional increment of damage occurring during the ith set of load and materials conditions. The Miner's law concept can be explained fairly easily by an example. The following example examines an asphalt concrete pavement layer and the fractional portions of fatigue life consumed during various seasons of the year.

A Simple Application of Miner's Law

In this example, let's first analyze the asphalt concrete pavement layer of a pavement structure using ELSYM5 and the TAI damage equation previously discussed (TAI applies to heavily bound layers). The pavement is analyzed for three sets of conditions (i = 1 through 3). The three sets of conditions are: spring, summer, and fall. ELSYM5 will be used to calculate the maximum tensile strain at the bottom of the asphalt concrete layer for each season, based on the properties of the materials (materials properties will be different for each season) and the design load. Using the maximum tensile strain calculated by ELSYM5 for each season, the TAI equation will be used to calculate the number of loads to fatigue failure (N_f) for each season. The actual number of load repetitions expected during each season (N_a) is known based on traffic forecasting, e.g., ESALs. The application of Miner's law is laid out in tabular form below.

Season	N_a	N_f	N_a/N_f
Spring	300,000	600,000	0.50
Summer	1,000,000	5,000,000	0.20
Fall	900,000	7,000,000	0.13

Miner's law summation is: $(N_a/N_f)_{spring} + (N_a/N_f)_{summer} + (N_a/N_f)_{fall} = 0.83$

Miner's law states that the failure will not occur unless: $\sum_{i=1}^{i=total} \left(N_a / N_f \right)_i \geq 1$

Therefore, the asphalt concrete pavement should not fail in fatigue with the expected number of load repetitions. Furthermore, the results indicate that no more than about 83% of the fatigue life of the asphalt concrete pavement will be consumed by the expected load repetitions.

4.4. Stepping Through the Design Process—An Example

1. The designer assembles design input data.

   a. Wheel configuration, tire pressure, and intensity of design load

      Dual tire load of 4,500 lbs/tire, with 90 psi tire pressure

      Tires separated 13.5 inches center-to-center

   b. Number of applied design load cycles expected during the pavement's design life (this total number is subdivided according to the percentages of load applications during spring, summer, fall, and winter)

      1,000,000 load repetitions total, subdivided as:

      30% in spring = 300,000 load repetitions = $N_{a,\ Spring}$

      50% in summer = 500,000 load repetitions = $N_{a,\ Summer}$

      20% in fall = 200,000 load repetitions = $N_{a,\ Fall}$

   c. M_R and μ of each layer in the proposed pavement structure (one set of these materials properties must be defined for each season of the year, i.e., spring, summer, fall, and winter)

Materials Properties Material Type	Thickness (inches)	Spring		Summer		Fall	
		M_R (ksi)	μ	M_R (ksi)	μ	M_R (ksi)	μ
Asphalt Concrete	3.5	754	0.30	508	0.30	508	0.30
Base Course	6	44	0.35	51	0.35	51	0.35
Subbase	36	26	0.40	36	0.40	36	0.40
Subgrade	Semi-I*	44	0.35	10	0.45	10	0.45

(* semi-infinite thickness)

d. Proposed thickness of each layer in the proposed pavement structure

Layer thicknesses are included in the above table

e. Asphalt concrete mix properties

density of asphalt concrete = 150 pcf

% asphalt cement by total weight of mix = 5.5

% air voids = 4

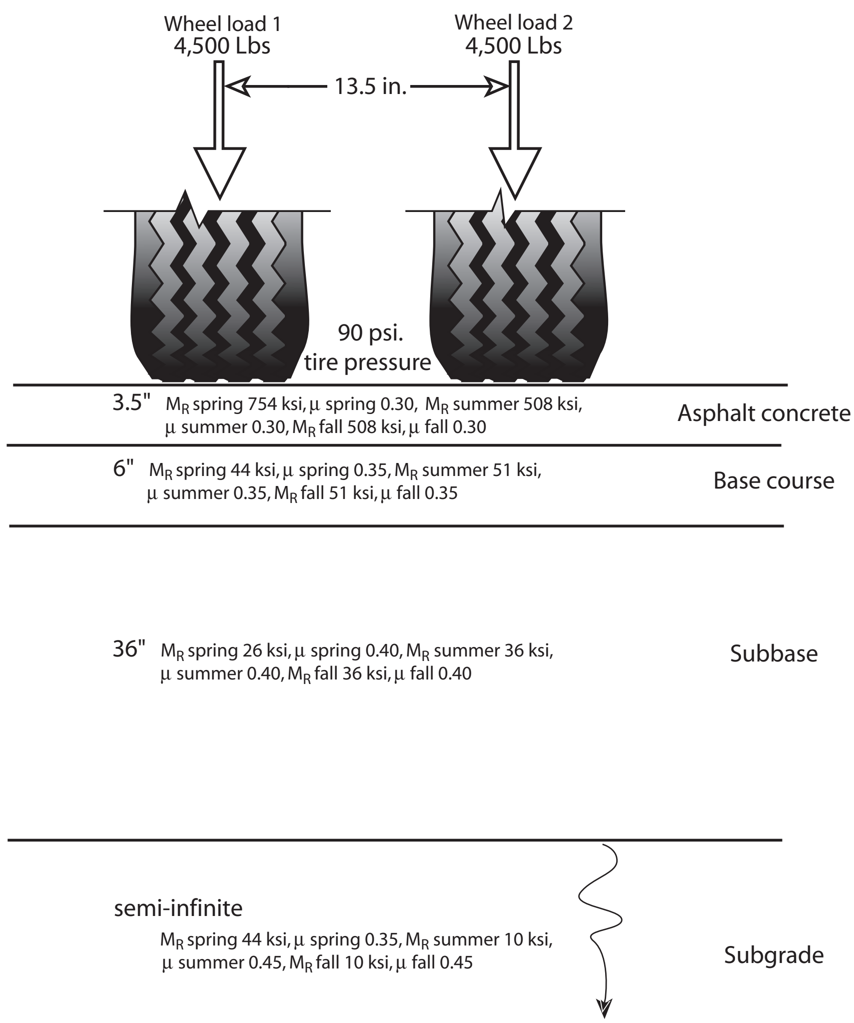


Figure 4-6. Pavement Structure Used in Example Problem

2. The designer loads data to AKFPD input screen and runs program.
3. AKFPD calculates response stresses and strains at critical locations within the pavement structure due to application of the design load. A separate set of response stresses and strains is calculated for each critical location and for each season, based on materials properties for that season.

Calculated Stresses and Strains

Season	Tensile Strain (micro-strain) at Critical Location	Compressive Stress (psi) at Critical Locations		
	Bottom of Asphalt Concrete (depth = 3.5”)	Top of Base (depth = 3.5”)	Top of Subbase (depth = 9.5”)	Top of Subgrade (depth = 45.5”)
Spring	192	26.4	11.6	1.9
Summer	202	33.5	13.6	1.0
Fall	202	33.5	13.6	1.0

4. AKFPD then calculates the number of times the design load can be applied before all of the pavement’s life is expended and pavement failure occurs. The number of allowable loads is separately calculated for each critical location and for each season, using the previously calculated stresses and strains as input values to empirical damage equations (transfer functions).

Calculated Loads to Failure

Season	Loads to Failure, N_f, Based on Analyses at Critical Locations			
	For Asphalt Concrete	For Base Course	For Subbase	For Subgrade
Spring	3,030,000	2,090,000	5,480,000	11,094,000,000
Summer	3,590,000	1,550,000	9,430,000	467,510,000
Fall	3,590,000	1,550,000	9,430,000	467,510,000

5. AKFPD then calculates seasonal **fractional amounts** of pavement life expended (seasonal damage fractions) by dividing the number of design loads for each season by the number of allowable loads for that season.

Calculate Fractions of Pavement Life Expended During Each Season

Season	N_a/N_f Based on Analyses at Critical Locations			
	For Asphalt Concrete	For Base Course	For Subbase	For Subgrade
Spring	3.00e5 / 3.03e6 = 0.099	3.00e5 / 2.09e6 = 0.144	3.00e5 / 5.48e6 = 0.055	3.00e5 / 1.11e10 = 0.00003
Summer	5.00e5 / 3.59e6 = 0.139	5.00e5 / 1.55e6 = 0.323	5.00e5 / 9.43e6 = 0.053	5.00e5 / 4.68e8 = 0.00107
Fall	2.00e5 / 3.59e6 = 0.056	2.00e5 / 1.55e6 = 0.129	2.00e5 / 9.43e6 = 0.021	2.00e5 / 4.68e8 = 0.00043

6. AKFPD next applies Miner’s law to determine **total amount** of pavement life expended by adding together the seasonal fractions. According to Miner’s law, the pavement has failed if this total damage summation for any layer of material is ≥ 1.

Using Miner's Law, Sum Up Seasonal Damage Fractions

Season	Sum Damage: $(N_a/N_f)_{spring} + (N_a/N_f)_{summer} + (N_a/N_f)_{fall}$ Based on Analyses at Critical Locations			
	For Asphalt Concrete	**For Base Course**	**For Subbase**	**For Subgrade**
Spring	0.099	0.144	0.055	0.00003
Summer	0.139	0.323	0.053	0.00107
Fall	0.056	0.129	0.021	0.00043
Miner's Law Damage Summation for Each Column	0.294	0.596	0.129	0.00153

Interpreting Miner's law for this example: Miner's law states that the pavement structure will fail if the damage summation for any critical location exceeds 1, i.e., $\sum_{i=1}^{i=total} \left({N_a}/{N_f} \right)_i \geq 1$

In this example, damage sums do not exceed 1 for any critical location. The proposed design is therefore structurally acceptable. Select the most economical design (using life-cycle cost analysis) from several different designs that are found to be structurally acceptable (using mechanistic design).

In addition to determining acceptability or unacceptability of the proposed pavement structure, Miner's law provides some useful insight into the structure's behavior. Referring to the previous table, one can determine which critical locations (and therefore which materials) are controlling acceptability of the proposed design. In this case, the damage summation assessed at the top of the subgrade is near zero at less than 0.2% (table sum = 0.00153), showing that the subgrade is essentially completely protected from load effects by overlying structural layers. We can see that the asphalt concrete pavement has received enough load repetitions to use up about 30% (table sum = 0.294) of its available life, and that 60% (table sum = 0.596) of the base course's life has been exhausted. Such information can help you predict which failure modes are most probable in the future.

If the total damage summation had been ≥ 1 for any layer of material, the pavement structure (as a whole) cannot withstand the required number of cycles of the design load. In that case the designer would rerun the program using different sets of input variables, such as different aggregate layer thicknesses, higher quality aggregate materials, thicker asphalt concrete pavement, etc., until the total damage summation for each layer of material is less than 1.

4.5. Overlaying an Existing Asphalt Concrete Layer

Pavement overlay involves placing an additional (new) asphalt concrete pavement layer on top of an existing asphalt concrete layer. The new total thickness is designed to withstand a specified number of future design load repetitions. The method of designing the required thickness for the new layer accounts, mechanistically, for the amount of fatigue damage done to the old asphalt concrete layer by past load repetitions (before the overlay). You can choose to operate AKFPD in an overlay design mode. If operated in this mode, AKFPD will automatically calculate the required overlay thickness.

The process of determining an overlay thickness for an existing paved structure uses essentially the same series steps shown above. Conceptually, the old asphalt concrete layer simply becomes redefined as the second layer of a "new" pavement structure. AKFPD then determines the thickness of new pavement required to satisfy the structural requirements of future traffic. The minimum overlay thickness is 2.0 inch.

Refer to Section 2.2.3 for overlay design guidelines.

4.6. Mechanistic Design Using the AKFPD Computer Program

4.6.1. Generalized Steps Through the Program for Designing a New Pavement Structure

1. The designer assembles design input data:
   a. Wheel configuration, tire pressure, and load intensity of design load
   b. Number of design load cycles expected during the pavement's design life (this total number is subdivided according to the percentages of load applications during spring, summer, fall, and winter)
   c. M_R and μ of each layer in the proposed pavement structure (one set of these materials properties must be defined for each season of the year, i.e., spring, summer, fall, and winter)
   d. Asphalt concrete mix properties
   e. Proposed thickness of each layer in the pavement structure
2. The designer loads data to AKFPD input screen and runs program.
3. AKFPD calculates response stresses and strains at critical locations within the pavement structure due to application of the design load. A separate set of response stresses and strains is calculated for each season based on materials properties for that season.
4. AKFPD then calculates allowable loads, i.e., the number of times the design load can be applied before the pavement's life is 100% expended and pavement failure occurs. A separate set of allowable loads is calculated for each season using the previously calculated stresses and strains as input values to empirical damage equations (sometimes called transfer functions).
5. AKFPD then calculates seasonal **fractional amounts** of pavement life expended (seasonal damage fractions) by dividing the number of design loads for each season by the number of allowable loads for that season.
6. AKFPD next applies Miner's law to determine **total amount** of pavement life expended by adding together the seasonal fractions. According to Miner's law, the pavement has failed if this "total damage summation" is ≥ 1.
7. If the total damage summation is ≥ 1, the pavement structure is not sufficient to withstand the required number of cycles of the design load. Rerun the program using different sets of input variables, e.g., different aggregate layer thicknesses, higher quality aggregate materials, thicker asphalt concrete pavement, etc., until the total damage summation is less than 1.

4.6.2. Example 1—Getting Started and Performing a Simple Design

The following steps lead you through a simple example of AKFPD mechanistic pavement design analysis and interpretation of the results.

This design example does not use a previously saved input data file. In other examples, you will explore use and modification of previously saved input data files.

You will gain cumulative experience by going through each design example in turn because each successive example builds on information and tips contained in the previous one.

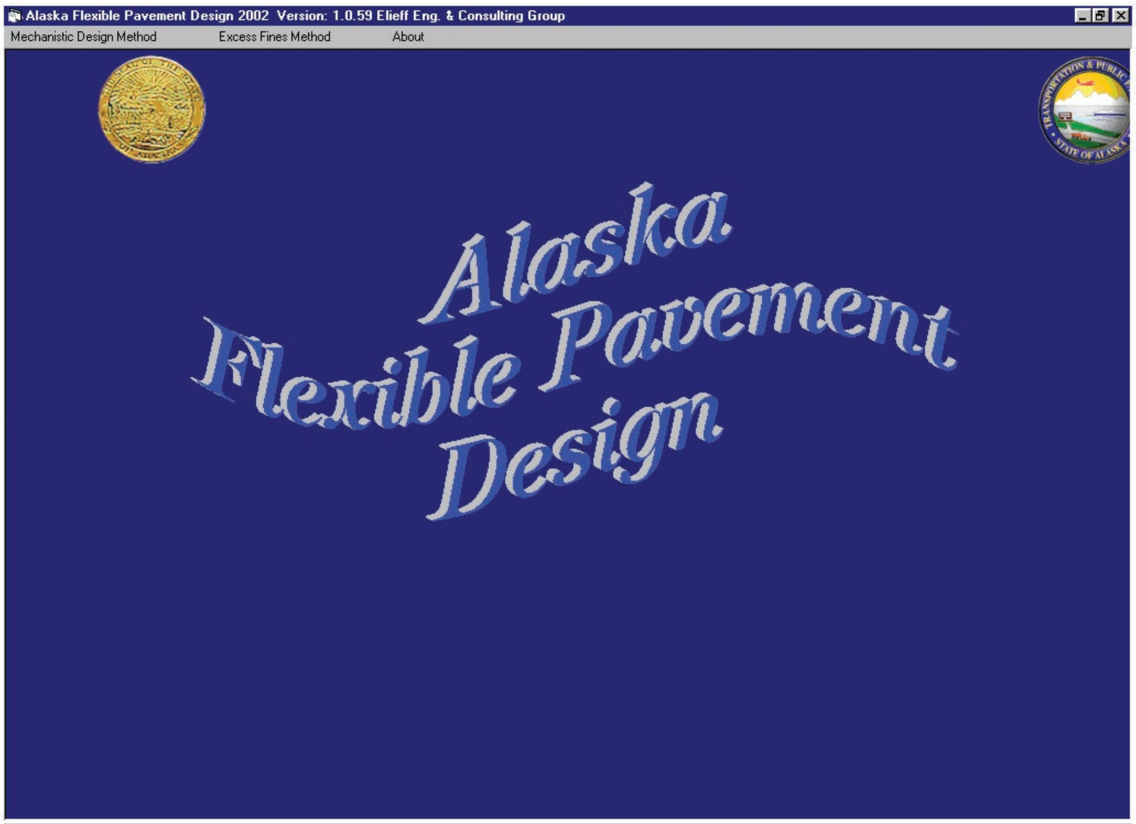
Mouse clicks are single clicks of the left button of the computer mouse configured in the standard operating mode.

Step 1. Insert the AKFPD program CD disk into one of your computer's CD drives.

Step 2. Install AKFPD onto your computer. If the software does not autoload, locate a listing of the CD's contents using the Windows ***My Computer Explore*** feature and run the program "setup.exe" file. Alternatively, use the Windows ***Start Run*** feature by typing in the appropriate CD disk drive and the filename "setup.exe." *The program can be removed by accessing the **Start Control Panel** feature of your computer, then selecting **Add/Remove***

Programs. *From the list of installed programs select "Alaska Flexible Pavement Design 2002" and proceed with the uninstall process.*

Step 3. Run AKFPD. Initiate the ***Start Programs*** feature of Windows, and from the listing of programs shown on your computer, run the program "Alaska Flexible Pavement Design 2002." The AKFPD title screen will appear as shown in Screen Clip 4-1.



Screen Clip 4-1

Step 4. Near the top left corner of the introductory screen, two program design method options are offered. One of the options is labeled ***Mechanistic Design Method.*** Using your mouse, click on that option. The pull-down menu shown in Screen Clip 4-2 will appear.

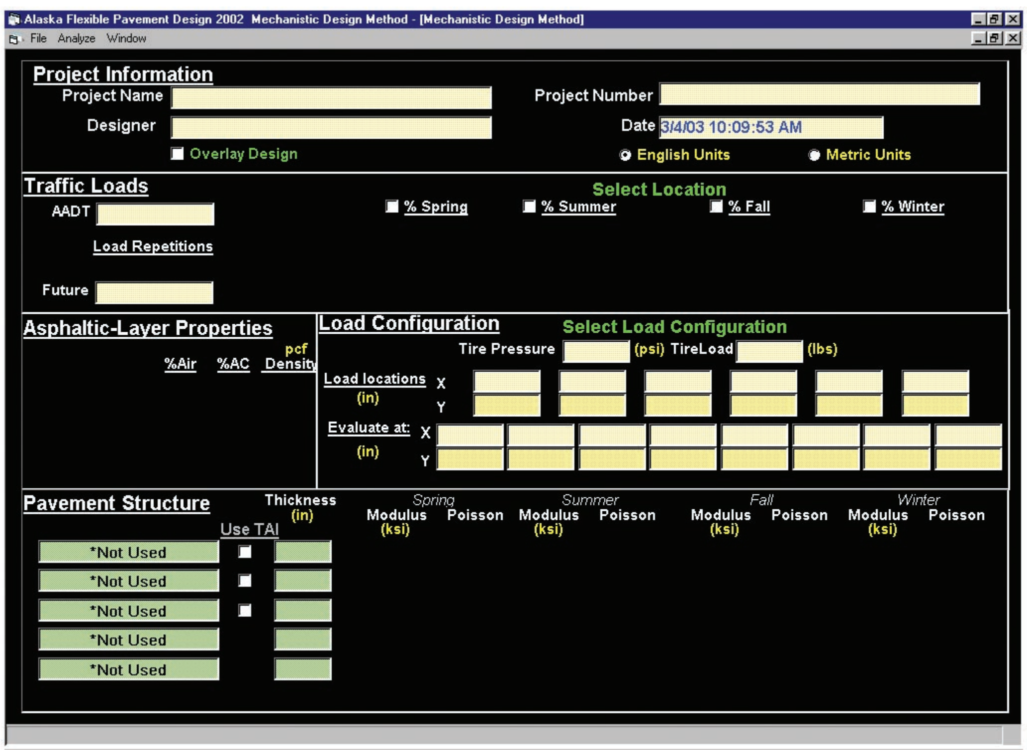
Screen Clip 4-2

Step 5. You now have two new options:

1. Click on ***New Analysis*** to begin a completely new mechanistic pavement design. A blank design input data screen will appear, which must be completely filled in by the designer before performing the analysis.

2. Click on ***Open Existing*** to begin an analysis using a previously saved input data file. The previously saved file can be opened then analyzed without modification, or the file can be opened and modified before analysis.

Step 6. This simple example uses the ***New Analysis*** option. Clicking on that one brings up the screen shown in Screen Clip 4-3.

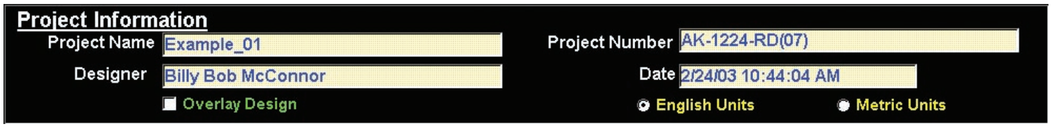


Screen Clip 4-3

Type all data items required for the complete mechanistic analysis into this screen indicated in Screen Clip 4-3. Select/deselect on the screen by clicking. The following steps explain input values necessary to fill various areas of the screen.

Step 7. Use the ***Project Information*** section of the screen (see Screen Clip 4-4) for entering project identification information. Along the bottom of that section are toggles for selecting the system of numerical units to be used and selecting (or deselecting) overlay design mode. To operate the toggles, fill or clear the appropriate boxes with appropriate clicks.

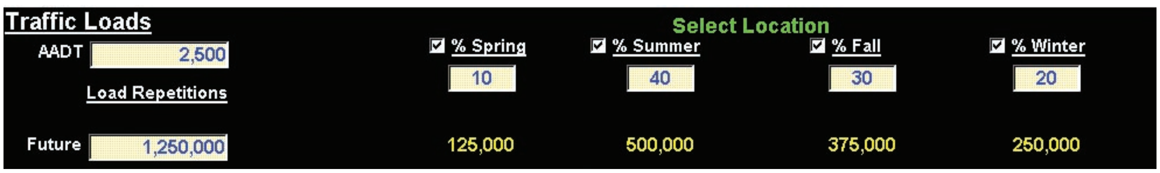
Fill the ***Project Name, Project Number,*** and ***Designer*** designator boxes with appropriate strings of standard alphanumeric characters as in Screen Clip 4-4. Select each box with the mouse pointer. A single mouse click initiates the typing prompt. AKFPD automatically updates the ***Date*** box.



Screen Clip 4-4

Because this is not an overlay design, note that the ***Overlay Design*** box remains clear. To continue with the example, use your mouse to designate applicable fields on your AKFPD input screen and type in the data indicated above.

Step 8. Use the ***Traffic Loads*** section of the input screen (see Screen Clip 4-5) for entering traffic frequency information. Select the ***AADT*** box using the mouse, and then type in the project's design average annual daily traffic number. Select the ***Future*** box. Type in the project's design ESALs.

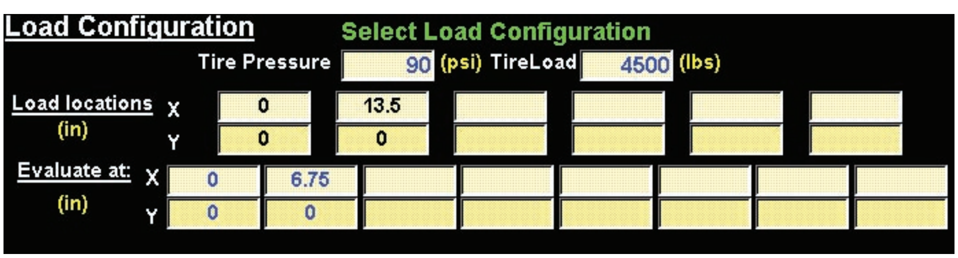


Screen Clip 4-5

The elasticity of the pavement structure varies with the seasons. Therefore, the amount of wear caused to the pavement structure by a given number of vehicle loads is more or less severe depending on the season the load is applied. Therefore, the project's design ESAL number entered into the ***Future*** box must be seasonally subdivided to designate percentages of the total future ESAL (1,250,000) that are applied in each season. To allocate design ESAL percentages for each season, first click on each of the small boxes immediately to the left of each season identifier (see Screen Clip 4-5). As you click each box, a check mark will appear beside the season identifiers. Next, use the mouse to designate, for data entry, each of the boxes located below the season identifiers. Within each box, enter the desired percentages as shown in Screen Clip 4-5.

To continue with the example, use your mouse to designate applicable fields on your AKFPD input screen and enter the data shown in Screen Clip 4-5.

Step 9. Use the ***Load Configuration*** section of the input screen, shown in Screen Clip 4-6, for entering the characteristics of the design load and the x, y locations (in plan view) where pavement structural response will be calculated. This example is in English units so x, y coordinates are in inches.



Screen Clip 4-6

Under ***Select Load Configuration,*** enter data representing a simple dual-wheel design load. The load used in this example is the modified* ESAL normally used by DOT&PF for highway design. A ***Tire Pressure*** of 90 psi and ***Tire Load*** (for each tire) of 4,500 pounds is used.

> ** The modified ESAL load provides a slightly more severe, and therefore conservative, condition than the 80-psi tire pressure once used for DOT&PF highway pavement designs. Nowadays, 110-psi pressure represents current practice within the trucking industry.*

Use boxes located right of ***Load locations,*** in Screen Clip 4-6, for designating x, y coordinates (plan view) for the center of each of the tire loads. The x, y coordinates used in this example indicate that the tire centers are separated by 13.5 inches. Therefore, coordinates describing these tire locations are 0, 0 and 13.5, 0.

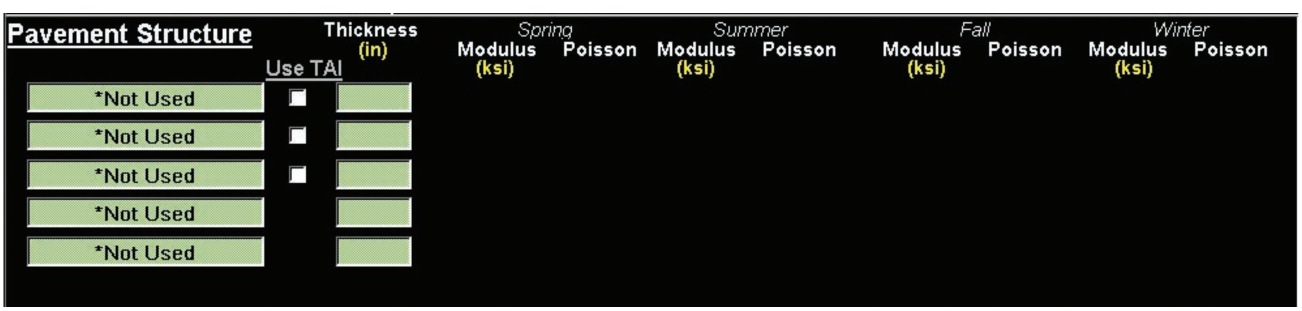
Use boxes located right of ***Evaluate at,*** in Screen Clip 4-6, for designating the plan view locations, within the pavement structure, to be analyzed for structural response. This example uses two locations. One location for analysis is directly under one of the wheel loads (use x, y coordinates of 0, 0). The second location is halfway between the wheel loads (use x, y coordinates of 6.75, 0).

Why not also evaluate structural response directly under the second wheel (at x, y coordinates of 13.5, 0)? By inspection you can see that the dual wheel configuration is symmetrical about two lines (see symmetry shown for two *loads* in Figure 4-4). One line of symmetry passes through the wheel centers, while the second line of symmetry is perpendicular to the previous line and located halfway between the wheel centers. Load symmetry indicates symmetry of structural response. Such symmetry indicates that the pavement structure's load response at coordinates 0, 0 and 13.5, 0 will be the same.

To continue with the example, use your mouse to designate applicable fields on your AKFPD input screen and type in the data indicated shown in Screen Clip 4-6.

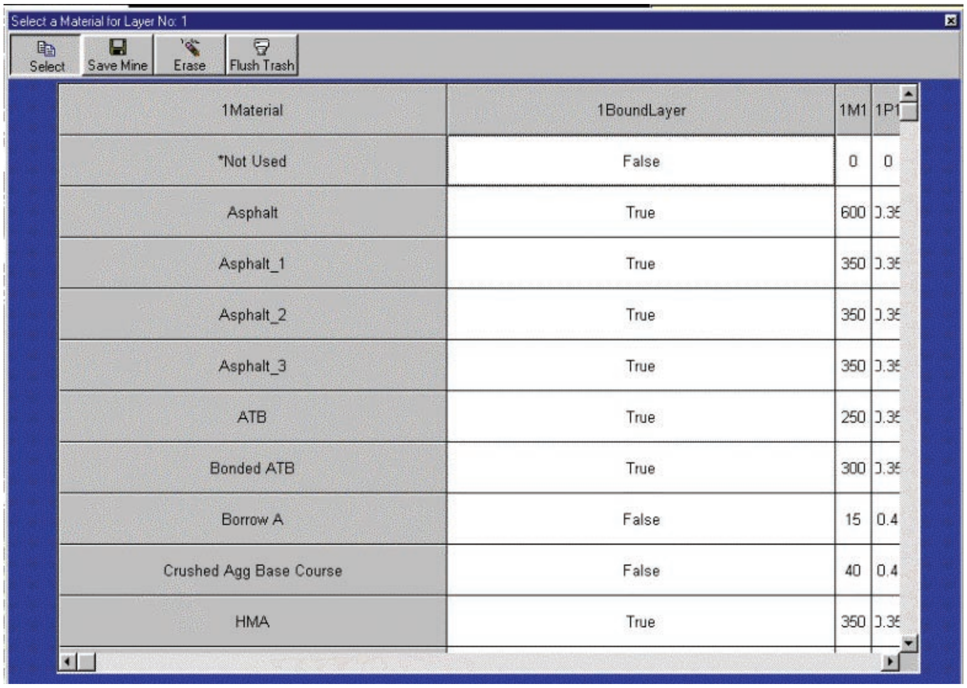
Step 10. Use the ***Pavement Structure*** section of the input screen shown in Screen Clip 4-7 for entering the characteristics of each layer of material in the pavement structure. You can define up to five layers. Each layer is defined by its thickness and also by its resilient modulus (M_R) and Poisson's ration (μ) for each season of design load application (check your input screen against Step 8 of this example to verify that you have activated spring, summer, fall, and winter seasons as shown).

To begin entering materials properties, click the top left box labeled **** Not Used*** (shown in Screen Clip 4-7).



Screen Clip 4-7

An auxiliary menu containing materials properties will appear as shown in Screen Clip 4-8.



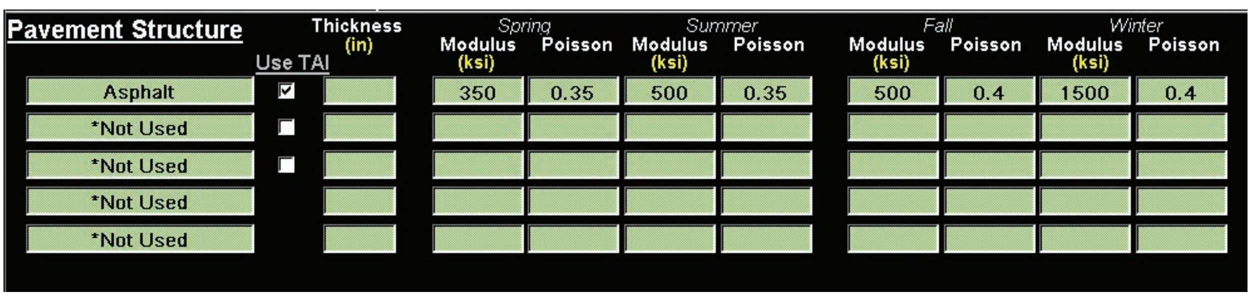
Select a Material for Layer No: 1

Select | Save Mine | Erase | Flush Trash

1Material	1BoundLayer	1M1	1P1
*Not Used	False	0	0
Asphalt	True	600	0.35
Asphalt_1	True	350	0.35
Asphalt_2	True	350	0.35
Asphalt_3	True	350	0.35
ATB	True	250	0.35
Bonded ATB	True	300	0.35
Borrow A	False	15	0.4
Crushed Agg Base Course	False	40	0.4
HMA	True	350	0.35

Screen Clip 4-8

For this example, use the mouse to point and click at the material identified as ***Asphalt*** on the list. The menu will then disappear and presumptive M_R and μ values such as shown in Screen Clip 4-9 will appear.

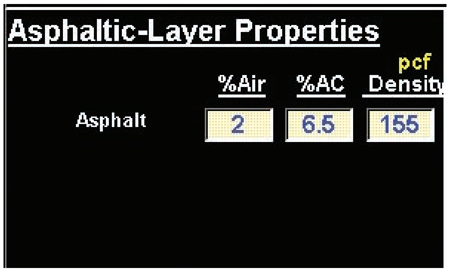


Pavement Structure	Use TAI	Thickness (in)	Spring Modulus (ksi)	Spring Poisson	Summer Modulus (ksi)	Summer Poisson	Fall Modulus (ksi)	Fall Poisson	Winter Modulus (ksi)	Winter Poisson
Asphalt	☑		350	0.35	500	0.35	500	0.4	1500	0.4
*Not Used	☐									
*Not Used	☐									
*Not Used										
*Not Used										

Screen Clip 4-9

Notice that a check mark has automatically been placed in the top box located in the ***Use TAI*** column. The check mark specifies that the TAI equation (see Section 4.3.2) will be used to calculate the number of design load repetitions until failure—this is the correct equation to use for normal asphalt concrete materials. The critical structural response parameter used in the TAI equation is tensile strain at the bottom of the layer.

When one of the materials receives a check mark in the ***Use TAI*** column, data fields will appear on the input screen section labeled ***Asphaltic-Layer Properties*** (see Screen Clip 4-10). You must enter data in each of these boxes because they are required variables in the TAI equation. If you have included default asphalt concrete mix properties in the database for the material type you selected, then values will appear automatically. If the database does not contain default mix properties, blank data fields will appear and you must type the appropriate mix data into each of the three data fields.

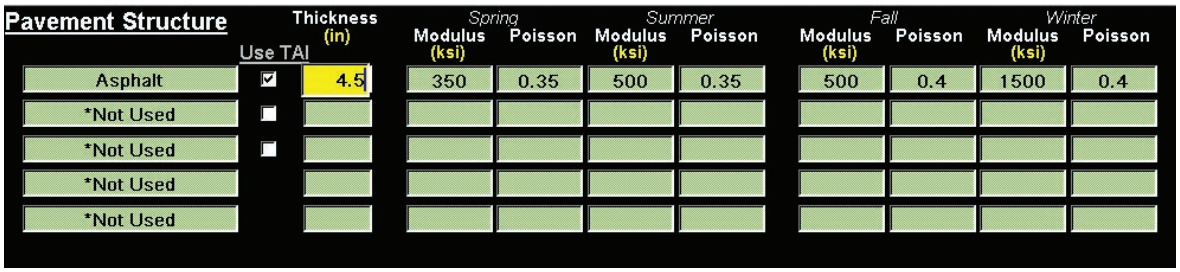


Asphaltic-Layer Properties

	%Air	%AC	pcf Density
Asphalt	2	6.5	155

Screen Clip 4-10

Now click in the upper box in the ***Thickness*** column and enter the 4.5-inch asphalt concrete thickness as shown in Screen Clip 4-11.

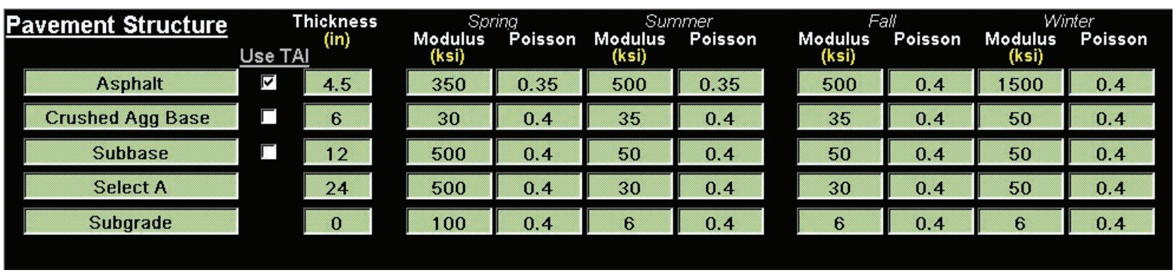


Pavement Structure

	Use TAI	Thickness (in)	Spring Modulus (ksi)	Spring Poisson	Summer Modulus (ksi)	Summer Poisson	Fall Modulus (ksi)	Fall Poisson	Winter Modulus (ksi)	Winter Poisson
Asphalt	☑	4.5	350	0.35	500	0.35	500	0.4	1500	0.4
*Not Used	☐									
*Not Used	☐									
*Not Used										
*Not Used										

Screen Clip 4-11

Enter properties for the remaining layers in the manner described above until you complete the data entry process as shown in Screen Clip 4-12.



Pavement Structure

	Use TAI	Thickness (in)	Spring Modulus (ksi)	Spring Poisson	Summer Modulus (ksi)	Summer Poisson	Fall Modulus (ksi)	Fall Poisson	Winter Modulus (ksi)	Winter Poisson
Asphalt	☑	4.5	350	0.35	500	0.35	500	0.4	1500	0.4
Crushed Agg Base	☐	6	30	0.4	35	0.4	35	0.4	50	0.4
Subbase	☐	12	500	0.4	50	0.4	50	0.4	50	0.4
Select A		24	500	0.4	30	0.4	30	0.4	50	0.4
Subgrade		0	100	0.4	6	0.4	6	0.4	6	0.4

Screen Clip 4-12

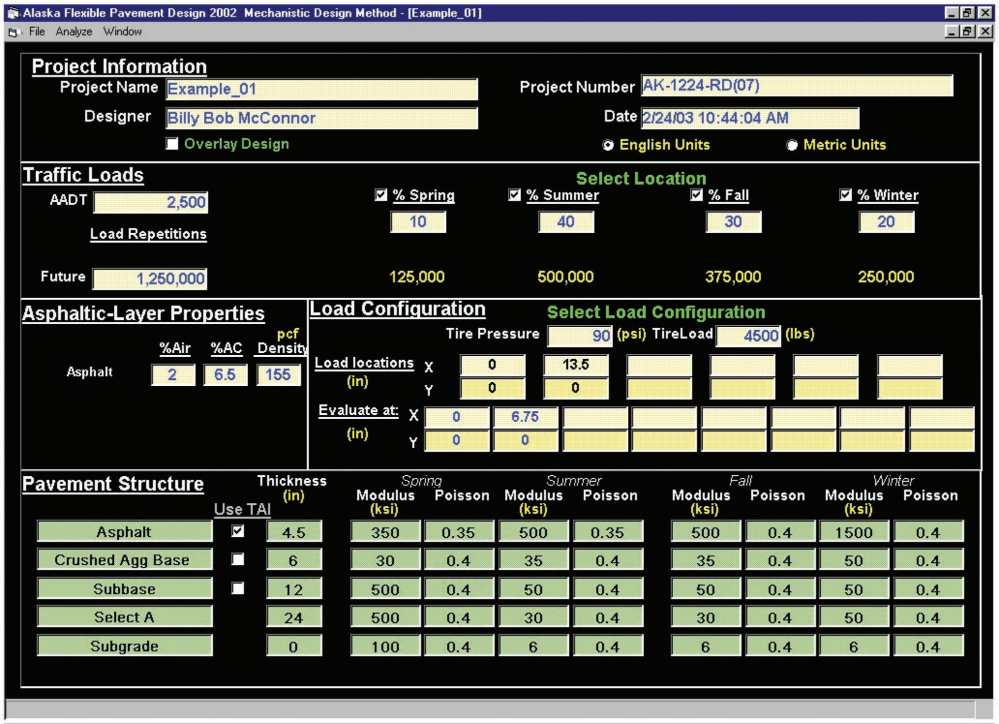
In this example, the thickness of the bottom layer is entered as 0. A thickness of 0 used for the bottom layer tells AKFPD that the bottom layer has infinite thickness. If you enter thickness other than 0 (48 inches, for example), AKFPD will assign the lower layer this thickness, and then automatically insert a hard surface (having infinite stiffness) under the bottom layer. When the hard surface is used, the AKFPD analysis automatically assumes a condition of no slippage at the interface, i.e., the bottom layer is assumed fully bonded to the hard surface.

If data obtained from the menu is different than that shown in Screen Clip 4-12, click in any box and you can change the number as desired. The menu selections contain default data that you can change.

In Screen Clip 4-12, notice that check marks are not automatically placed in the ***Use TAI*** column when the materials selected are not asphalt concrete types. When no check mark is entered for a material, the Per Ullidtz equation (see Section 4.3.2) will be used to calculate the number of design load repetitions until failure—this is the correct equation to use for normal aggregate or soil materials or for lightly stabilized materials containing less than 3% asphalt cement. The critical structural response parameter used in the Per Ullidtz equation is compressive stress at the top of the layer.

To continue with the example, use your mouse to designate applicable fields on your AKFPD input screen and type in the data indicated on Screen Clip 4-12.

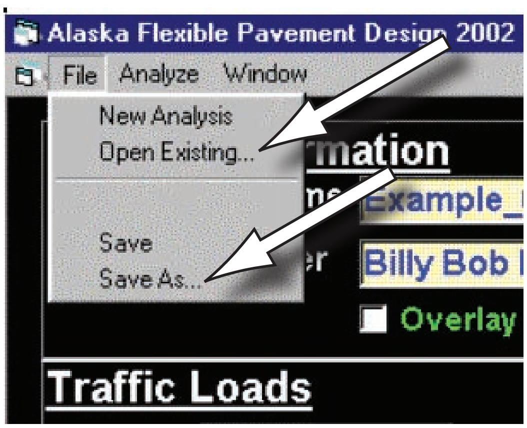
Step 11. Your completed input screen should look like the one shown as Screen Clip 4-13. If it does not, use your mouse to designate fields where data will need to be changed. Enter corrections until your input screen appears exactly as shown.



Screen Clip 4-13

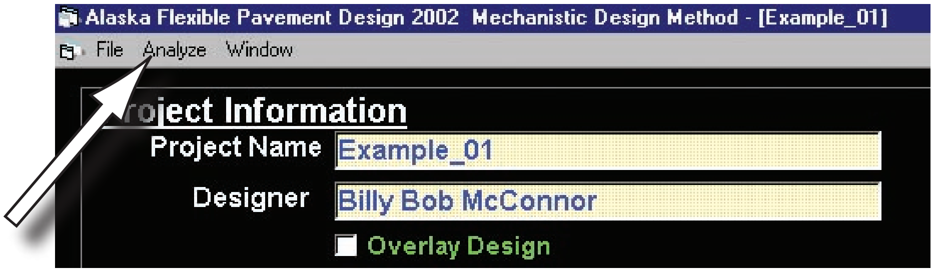
When you complete the input screen as indicated, you are ready to analyze the input data.

Step 12. You may now save your input data screen by accessing the ***File, Save As*** commands indicated in Screen Clip 4-14. Once saved, the input screen can be opened later using the ***File, Open Existing*** commands and analyzed as explained below. The input screen can also be opened and the data modified before analysis. Section 4.6.3 further explains the process of saving and recalling data.



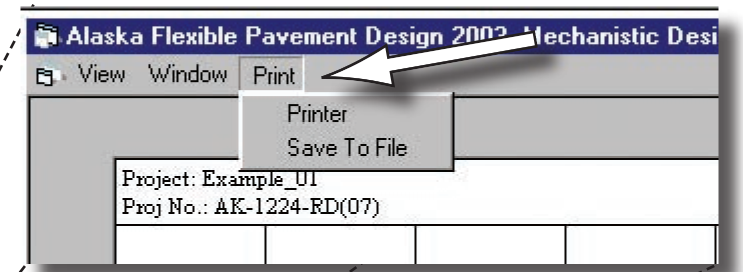
Screen Clip 4-14

Step 13. Perform the analysis and print the results. You are ready to initiate the computation process by clicking the ***Analyze*** button at the top left corner of the input screen shown in Screen Clip 4-15.

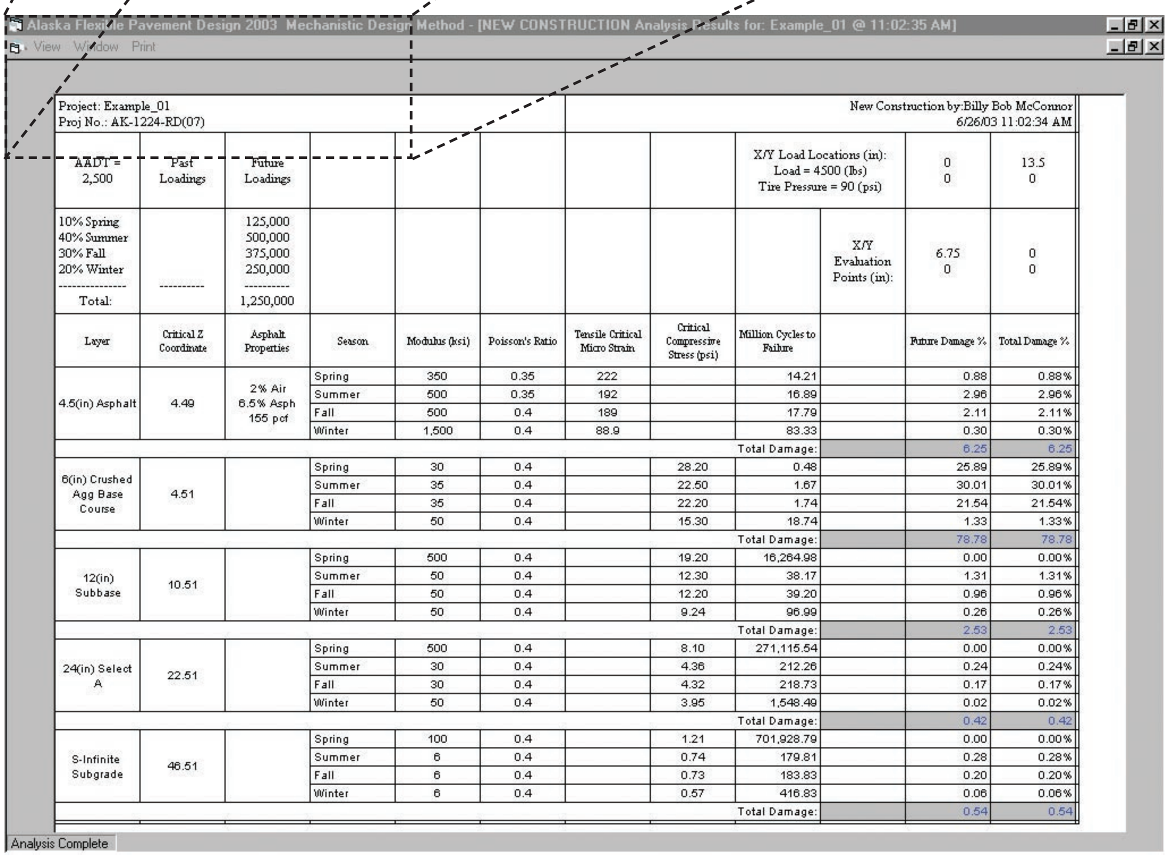


Screen Clip 4-15

The output screen shown as Screen Clip 4-16 will appear. You can print the screen in a format suitable for presentation by clicking the ***Print*** button at the top left corner of the output screen.



Screen Clip 4-15A



Project: Example_01 Proj No.: AK-1224-RD(07)						New Construction by:Billy Bob McConnor 6/26/03 11:02:34 AM					
AADT = 2,500	Past Loadings	Future Loadings						X/Y Load Locations (in): Load = 4500 (lbs) Tire Pressure = 90 (psi)		0 0	13.5 0
10% Spring 40% Summer 30% Fall 20% Winter -------------- Total:	----------	125,000 500,000 375,000 250,000 ---------- 1,250,000							X/Y Evaluation Points (in):	6.75 0	0 0
Layer	Critical Z Coordinate	Asphalt Properties	Season	Modulus (ksi)	Poisson's Ratio	Tensile Critical Micro Strain	Critical Compressive Stress (psi)	Million Cycles to Failure		Future Damage %	Total Damage %
4.5(in) Asphalt	4.49	2% Air 6.5% Asph 155 pcf	Spring	350	0.35	222		14.21		0.88	0.88%
			Summer	500	0.35	192		16.89		2.96	2.96%
			Fall	500	0.4	189		17.79		2.11	2.11%
			Winter	1,500	0.4	88.9		83.33		0.30	0.30%
								Total Damage:		6.25	6.25
6(in) Crushed Agg Base Course	4.51		Spring	30	0.4		28.20	0.48		25.89	25.89%
			Summer	35	0.4		22.50	1.67		30.01	30.01%
			Fall	35	0.4		22.20	1.74		21.54	21.54%
			Winter	50	0.4		15.30	18.74		1.33	1.33%
								Total Damage:		78.78	78.78
12(in) Subbase	10.51		Spring	500	0.4		19.20	16,264.98		0.00	0.00%
			Summer	50	0.4		12.30	38.17		1.31	1.31%
			Fall	50	0.4		12.20	39.20		0.96	0.96%
			Winter	50	0.4		9.24	96.99		0.26	0.26%
								Total Damage:		2.53	2.53
24(in) Select A	22.51		Spring	500	0.4		8.10	271,115.54		0.00	0.00%
			Summer	30	0.4		4.36	212.26		0.24	0.24%
			Fall	30	0.4		4.32	218.73		0.17	0.17%
			Winter	50	0.4		3.95	1,548.49		0.02	0.02%
								Total Damage:		0.42	0.42
S-Infinite Subgrade	46.51		Spring	100	0.4		1.21	701,928.79		0.00	0.00%
			Summer	6	0.4		0.74	179.81		0.28	0.28%
			Fall	6	0.4		0.73	183.83		0.20	0.20%
			Winter	6	0.4		0.57	416.83		0.06	0.06%
								Total Damage:		0.54	0.54

Screen Clip 4-16

Step 14. The upper portion of the output screen documents several types of input data. Included are project identification, load description data, specified evaluation locations, design AADT, design ESALs data, and seasonal percentages of ESAL application. These are shown in Screen Clip 4-17.

Project: Example_01 Proj No.: AK-1224-RD(07)						New Construction by:Billy Bob McConnor 6/26/03 11:02:34 AM				
AADT = 2,500	Past Loadings	Future Loadings						X/Y Load Locations (in): Load = 4500 (lbs) Tire Pressure = 90 (psi)	0 0	13.5 0
10% Spring 40% Summer 30% Fall 20% Winter --------------- Total:	 ---------- 	125,000 500,000 375,000 250,000 ---------- 1,250,000						X/Y Evaluation Points (in):	6.75 0	0 0

Screen Clip 4-17

Step 15. The bottom portion of the screen contains the results of the mechanistic analysis as shown in Screen Clip 4-18. For further discussion, the output screen's columns are numbered 1 through 11.

1	2	3	4	5	6	7	8	9		10	11
Layer	Critical Z Coordinate	Asphalt Properties	Season	Modulus (ksi)	Poisson's Ratio	Tensile Critical Micro Strain	Critical Compressive Stress (psi)	Million Cycles to Failure		Future Damage %	Total Damage %
4.5(in) Asphalt	4.49	2% Air 6.5% Asph 155 pcf	Spring	350	0.35	222		14.21		0.88	0.88%
			Summer	500	0.35	192		16.89		2.96	2.96%
			Fall	500	0.4	189		17.79		2.11	2.11%
			Winter	1,500	0.4	88.9		83.33		0.30	0.30%
								Total Damage:		6.25	6.25
6(in) Crushed Agg Base Course	4.51		Spring	30	0.4		28.20	0.48		25.89	25.89%
			Summer	35	0.4		22.50	1.67		30.01	30.01%
			Fall	35	0.4		22.20	1.74		21.54	21.54%
			Winter	50	0.4		15.30	18.74		1.33	1.33%
								Total Damage:		78.78	78.78
12(in) Subbase	10.51		Spring	500	0.4		19.20	16,264.98		0.00	0.00%
			Summer	50	0.4		12.30	38.17		1.31	1.31%
			Fall	50	0.4		12.20	39.20		0.96	0.96%
			Winter	50	0.4		9.24	96.99		0.26	0.26%
								Total Damage:		2.53	2.53
24(in) Select A	22.51		Spring	500	0.4		8.10	271,115.54		0.00	0.00%
			Summer	30	0.4		4.36	212.26		0.24	0.24%
			Fall	30	0.4		4.32	218.73		0.17	0.17%
			Winter	50	0.4		3.95	1,548.49		0.02	0.02%
								Total Damage:		0.42	0.42
S-Infinite Subgrade	46.51		Spring	100	0.4		1.21	701,928.79		0.00	0.00%
			Summer	6	0.4		0.74	179.81		0.28	0.28%
			Fall	6	0.4		0.73	183.83		0.20	0.20%
			Winter	6	0.4		0.57	416.83		0.06	0.06%
								Total Damage:		0.54	0.54

Screen Clip 4-18

Column 1. Identifies the material used for each layer.

Column 2. Identifies depth location where critical stresses or strains are evaluated (see section 4.3.2). The critical structural response parameter used in the TAI equation is tensile strain at the bottom of the layer. The critical structural response parameter used in the Per Ullidtz equation is compressive stress at the top of the layer. Note that the locations of tops and bottoms of layers indicated in column 2 are not exactly at the layer interfaces. For computational purposes, the ELSYM5 program defines, at layer interfaces, the top of the lower layer as being located slightly downward into that layer—and defines bottom of the upper layer as being located slightly upward into that layer.

Column 3. Lists asphalt concrete mix properties for each layer that was analyzed using the TAI fatigue-performance equation.

Columns 4, 5, and 6. These identify, for each season, the resilient modulus (M_R), and Poisson's ratio (μ) assigned to the material identified in column 1. Units used for M_R are ksi. Poisson's ratio is unitless.

Column 7. Lists tensile strains at the base of asphalt-cemented layer(s) calculated for various seasons. Values show up in this column only when the ***Use TAI*** box on the input screen near the material type designator (discussed in step 10) has been checked. The TAI equation uses this value, along with asphalt mix properties specified on the input screen, for calculating the load-cycles-to-failure indicated in column 9. Units used in this column are micro-strain (μ-ε).

Column 8. Lists compressive stresses at the top of unbound or lightly bound aggregates or soils, calculated for various seasons. Values show up in this column only when the ***Use TAI*** box on the input screen near the material type designator (discussed in step 10) has ***not*** been checked. The Per Ullidtz equation uses this value for calculating the load-cycles-to-failure indicated in column 9. Units used in this column are psi.

Column 9. Lists the number of design load cycles-to-failure for each material type and for each season of design load application. Cycles-to-failure (N_f discussed in section 4.3.2) are calculated for each material type using either the TAI or the Per Ullidtz equation, as applicable. The TAI equation is used if the ***Use TAI*** box is checked on the input screen—otherwise, the AKFPD program defaults to the Per Ullidtz equation. Units used in this column are 10^6 cycles.

Column 10. Lists "future damage," i.e., the percentage of life actually used up by the design ESAL applications. Values in this column are calculated by dividing the seasonal design ESAL value by the seasonal cycles-to-failure value in column 9.

> Example: Springtime design ESALS to be applied to the pavement structure are 125,000 as shown in the top, left portion of the output screen (Screen Clip 4-17). At the top of column 9, the springtime loads-to-failure is shown as 14,210,000. Therefore, the percent of springtime fatigue damage reported for the asphalt concrete at the top of column 10 is:
>
> $(125{,}000/14{,}210{,}000) \times 100 \approx 0.88\%$

In addition to listing the percent damage for each season, seasonal damage percents are summed, for each material type, within the column. This sum is blue if < 100% and red if it is ≥ 100%. For each material type, the sum predicts the total percent of the pavement structure's load capacity that will be exhausted by application of the design ESALs.

Column 11 is not used in this example. It repeats the listing of values shown in column 10. Column 11 is used in overlay designs that involve placing a new layer of asphalt concrete surfacing atop an existing pavement structure. In overlay designs, column 11 presents the sum of two damage types. The sum includes "future damage" used by the future design ESALs (as in column 10) plus damage done by past ESALs to the existing pavement structure prior to overlay placement.

Step 16. Interpreting the results of the analysis requires inspection of damage percents listed in column 10 of Screen Clip 4-18. In this case, damage sums for all material layers are less than 100% (note on your computer screen that each sum is shown in blue). Because all damage sums are less than 100%, the structural load capacity will not be exceeded for any of the layers due to application of the design ESALs. In other words, none of the layers will fail. The effect of the design ESALs on each layer is now assessed based on column 10 data:

1. Asphalt concrete layer: Design ESALs will exhaust about 6% of the structural load capacity (life). ESALs applied during summer and fall seasons contribute most to the percentage.
2. Crushed aggregate base: Design ESALs will exhaust about 80% of the structural load capacity. ESALs applied during spring and summer seasons contribute most to the percentage.
3. Subbase: Design ESALs will exhaust about 2.5% of the structural load capacity. ESALs applied during summer and fall seasons contribute most to the percentage.

4. Select: Design ESALs will exhaust about 0.4% of the structural load capacity. ESALs applied during summer and fall seasons contribute most to the percentage.
5. Subgrade: Design ESALs will exhaust about 0.5% of the structural load capacity. ESALs applied during summer and fall seasons contribute most to the percentage.

Based on this analysis, only the base course is “working” very hard during the ESAL design life of the pavement structure. The base course layer is therefore considered to be the critical one in this example—the critical layer is so called because it controls the design. Since 80% structural life of the critical layer will be consumed by the 1,250,000 design ESAL loading, the example pavement structure should be able to withstand the following number of ESALs before failure:

$$1{,}250{,}000 / 0.8 \approx 1.5 \text{ million ESALs}$$

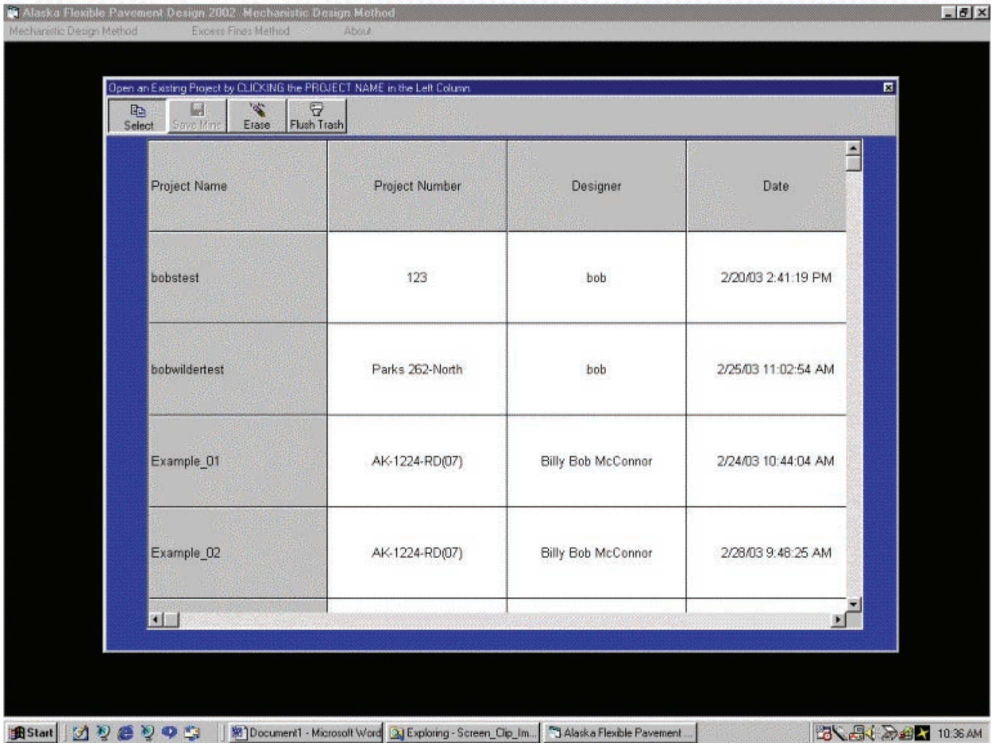
4.6.3 Saving, Recalling, and Modifying Files

Saving/Recalling the Input Screen

When you start the AKFPD program you can recall an existing data file (and modify it as necessary) instead of inputting new analysis data. Recall an existing file by accessing the ***Open Existing*** command on the ***Mechanistic Design Method*** pull-down menu from AKFPD’s opening screen as shown in Screen Clip 4-19.

Screen Clip 4-19

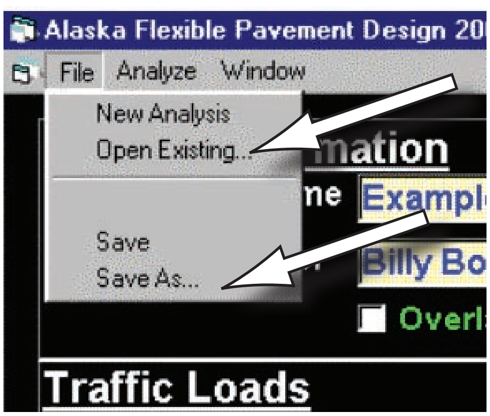
If you select the ***Open Existing*** option, a menu similar to the one shown in Screen Clip 4-20 appears. Click one of the data files to open it.



Screen Clip 4-20

Using the menu shown in Screen Clip 4-20, you can remove a data file from the menu by clicking on the menu's ***Erase*** button. Then mark one or more of the menu selections for removal and click on the ***Flush Trash*** button to permanently remove them from the menu.

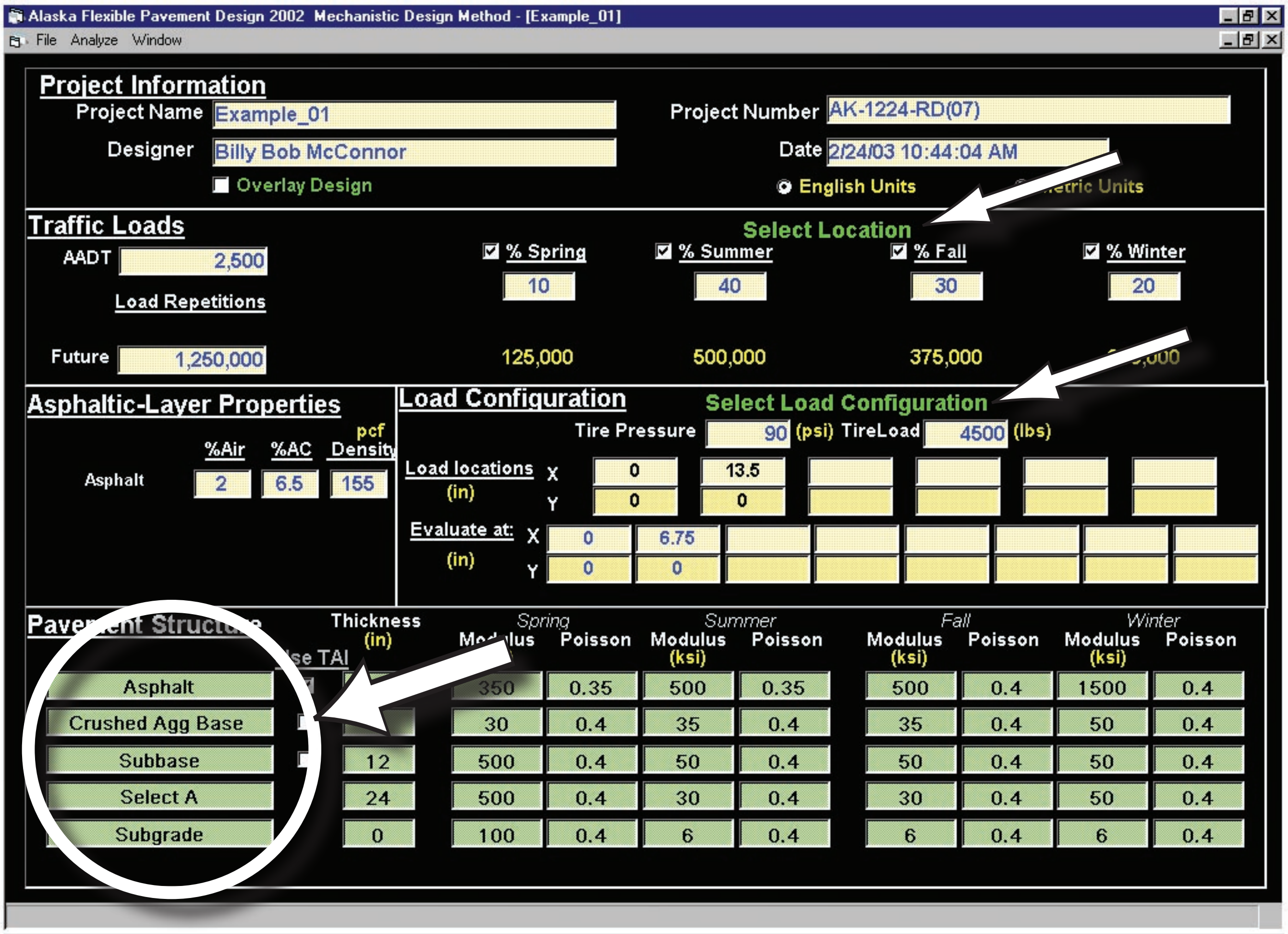
During the analysis you can save or open an existing data file. Save input screen data by accessing the ***File, Save As*** commands indicated in Screen Clip 4-21. Once saved, the input screen can be opened later using the ***File, Open Existing*** commands and analyzed as explained below. The input screen can also be opened and the data modified before analysis.



Screen Clip 4-21

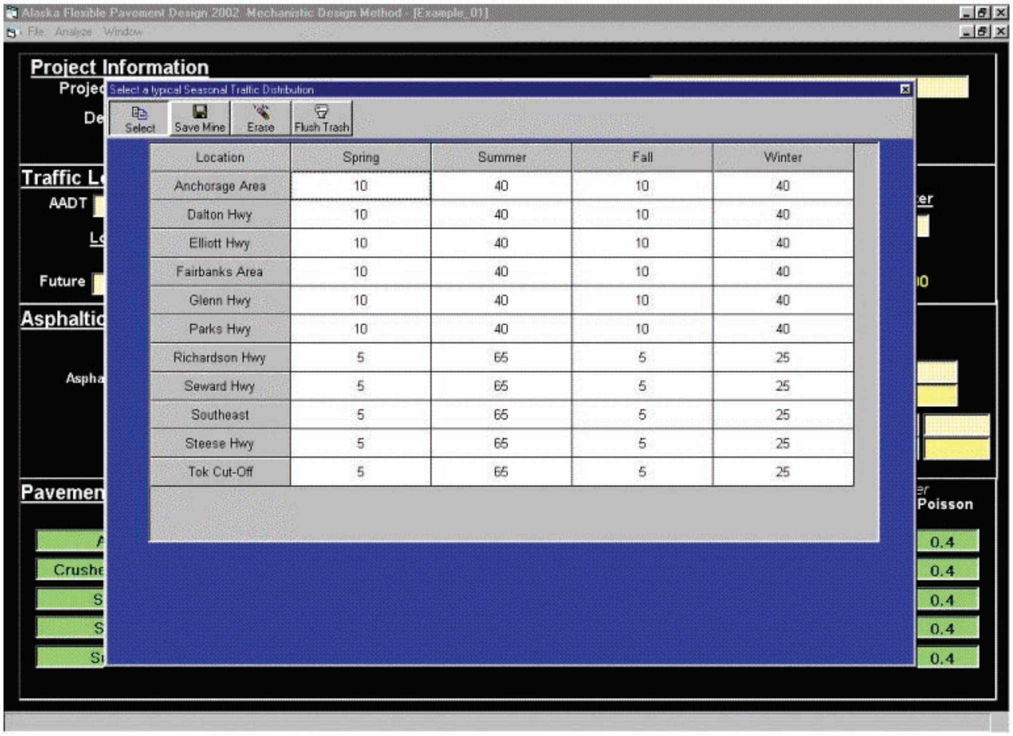
Saving, Recalling, and Modifying Auxiliary Menu Data

For three types of variables, you can activate auxiliary menus and choose from a catalog of previously saved data. Pointers located on the input screen shown as Screen Clip 4-22 (using example 1 input data) indicate which of the variable types can be selected. Initiate menu selection by clicking on (a) ***Select Location,*** (b) ***Select Load Configuration,*** or (c) any one of the five material identification boxes at the bottom left of the screen. Instructions at the end of this section describe how to perform add or delete data contained in auxiliary menu files, i.e., how to customize the auxiliary menus.



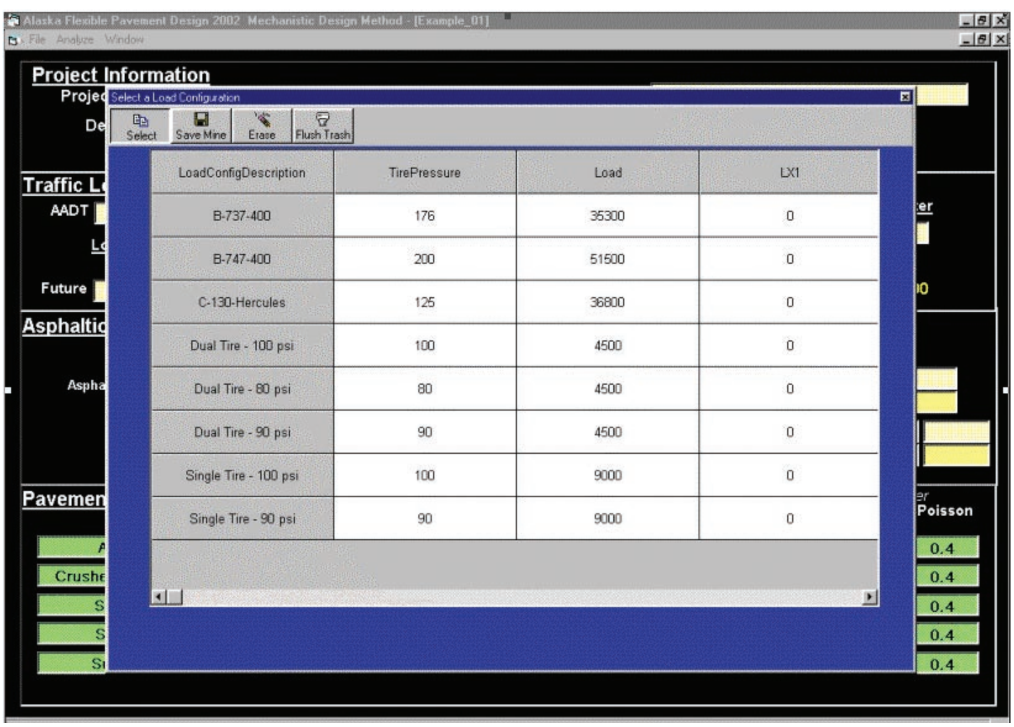
Screen Clip 4-22

Point and click on ***Select Location*** and the menu shown in Screen Clip 4-23 will appear. From here you can select a particular set of seasonal ESAL distributions.



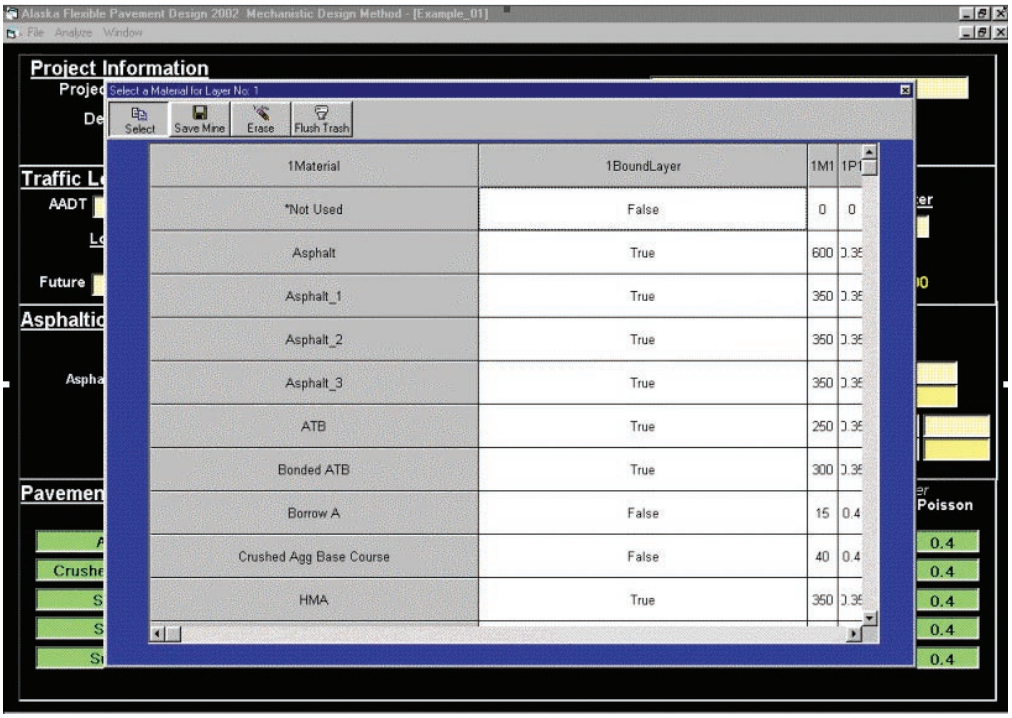
Screen Clip 4-23

Click on ***Select Load Configuration*** and a menu as in Screen Clip 4-24 will appear. From this menu you can select a complete design load configuration. Each data set in the menu includes variables describing the design load in terms of wheel weight, tire pressure, and tire location. The data also specify plan view x, y coordinates designating where structural response will be calculated. For each menu selection, all data necessary to complete the ***Load Configuration*** section of the input screen are included.



Screen Clip 4-24

Click on any of the five material types shown at the bottom of the input screen in Screen Clip 4-22 and a menu as shown in Screen Clip 4-25 will appear. From this menu the designer can select from one of the material types available. Except for layer thickness, each menu selection provides all data necessary to define the seasonal characteristics of a particular material type in the ***Pavement Structure*** section of the input screen.



Screen Clip 4-25

Adding Data to Auxiliary Menus: The auxiliary menu also allows you to save new data that you have entered on the input screen. To save new data, click on the auxiliary menu's ***Save Mine*** button. The new selection will show up on the auxiliary menu the next time it is activated. The described way of entering new menu data must be used because **you cannot enter new data by typing directly into an auxiliary menu screen**.

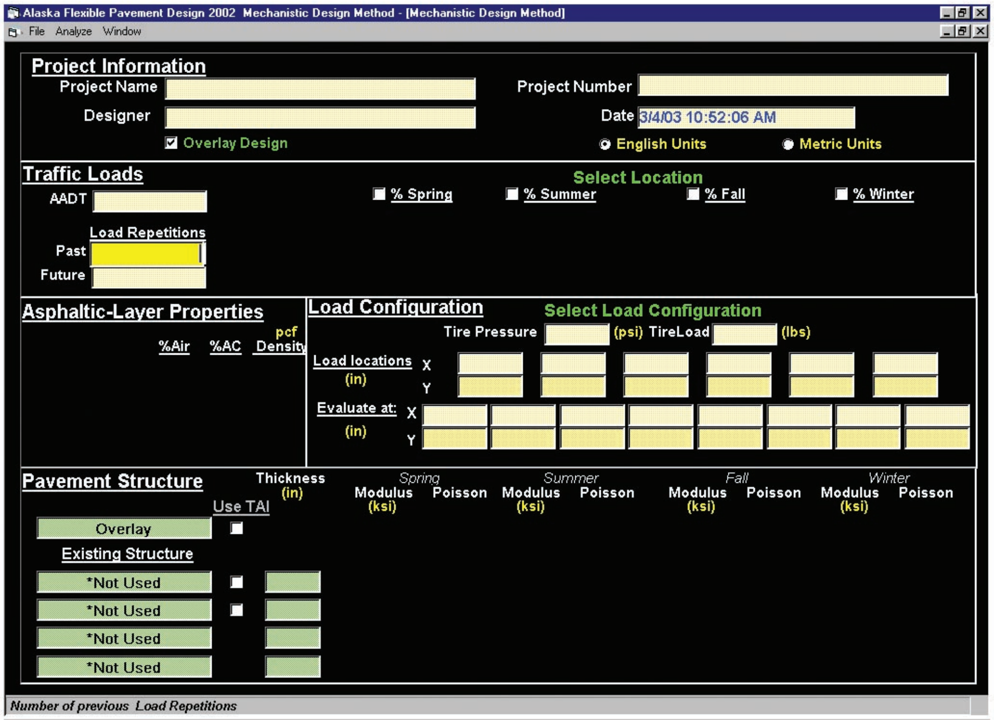
Deleting Data from Auxiliary Menus: You can remove data from the auxiliary menu by clicking on the menu's ***Erase*** button. Then mark one or more of the menu selections for removal, and click on the ***Flush Trash*** button.

4.6.4. Example 2—An Overlay Design

This example makes use of AKFPD's power to perform overlay design analyses. The concept of an overlay design is to determine how much pavement thickness needs to be added to an existing pavement to satisfy the requirements of future design ESALs. During the overlay design process, AKFPD accounts for the amount of structural life expended due to past ESAL applications. Past ESALs are those that were applied to the original pavement structure before the overlay placement.

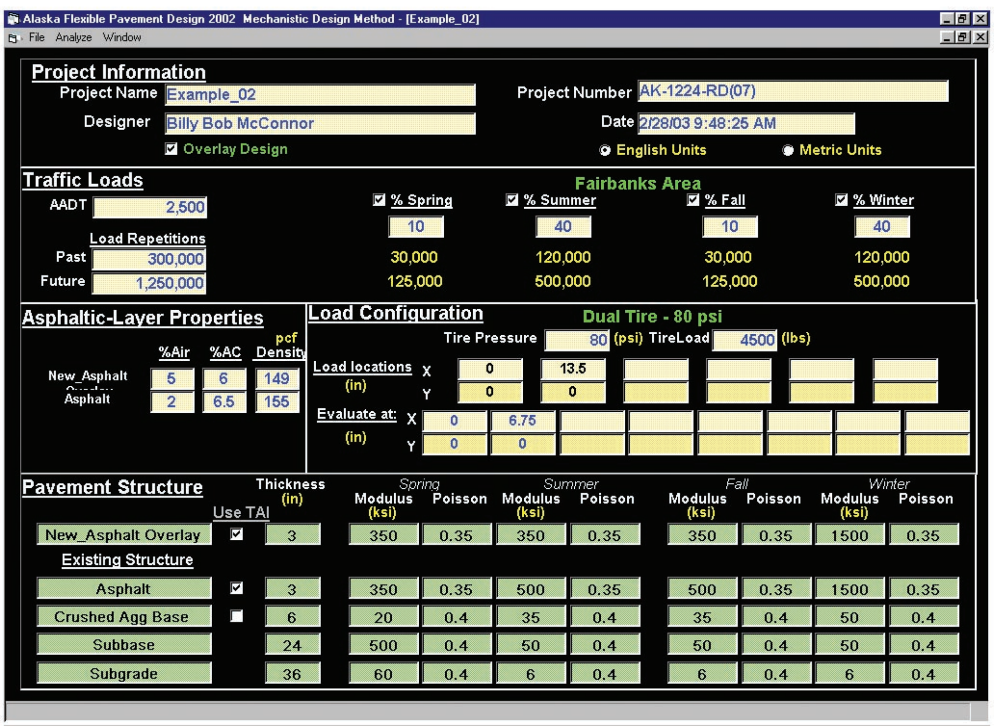
You will gain cumulative experience by going through each design example because each example builds on information and tips contained in the previous one. This example uses many of the program operation techniques presented in Section 4.6.2, example 1. **If you have not thoroughly familiarized yourself with example 1, do so before proceeding with this example.**

Step 1. Begin this example design by initiating the ***Mechanistic Design Method, New Analysis*** input screen as described in example 1. When the input screen appears, click on the ***Overlay Design*** toggle. The input screen will appear as shown in Screen Clip 4-26.



Screen Clip 4-26

Step 2. Using mouse and keyboard, enter input data for the example until the input screen is filled as shown in Screen Clip 4-27.



Screen Clip 4-27

Use mouse and keyboard to activate data input fields and input data as explained in example 1. However, the following tips may help expedite data entry within specific areas of the input screen:

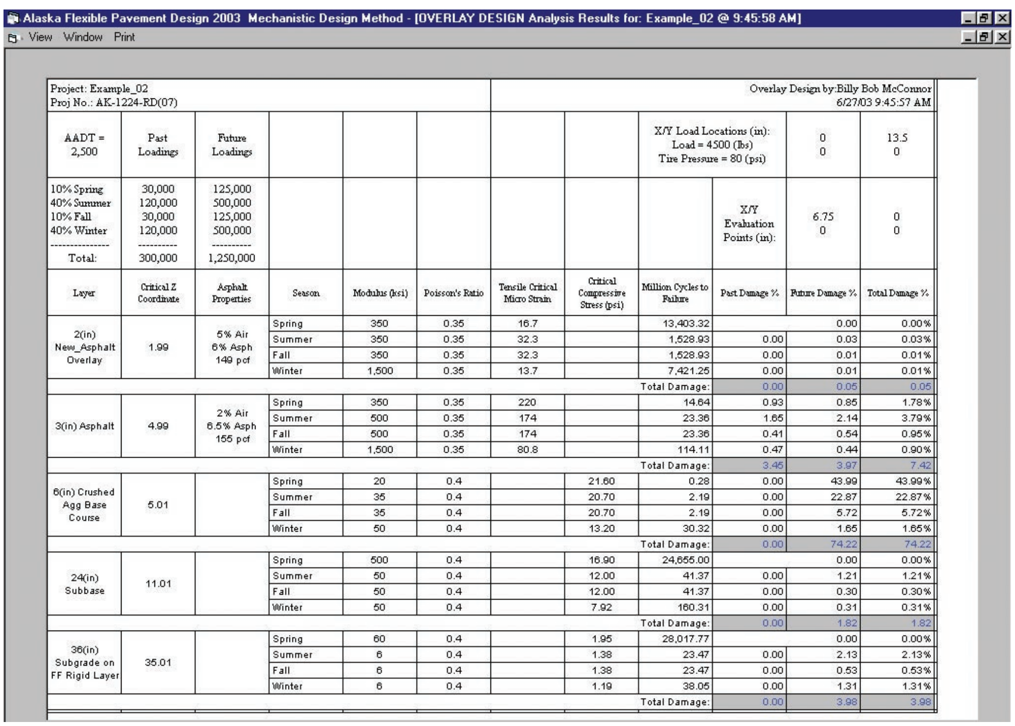
a. Tips for ***Traffic Loads*** section: As in the example, you can use an auxiliary menu to place data beneath the screen's ***Select Location*** designator. To do this, click on ***Select Location,*** and then select ***Fairbanks Area*** from the auxiliary menu. You do not need to use an auxiliary menu. You can click on each of the seasonal toggle boxes, and then type in the seasonal ESAL percents as shown in Screen Clip 4-27.

b. Tips for ***Load Configuration*** section: Click the left mouse button on the ***Select Load Configuration*** designator and then select from one of the choices on the auxiliary menu to fill applicable data boxes in the ***Load Configuration*** section. Alternatively, simply use mouse and keyboard to individually select and fill in the data entry fields exactly as shown in Screen Clip 4-27.

c. Tips for ***Pavement Structure*** section: Using auxiliary menus, select the material types shown in the example screen or use mouse and keyboard to select and fill in the data entry fields exactly as shown in Screen Clip 4-27. Be sure to use your mouse to activate the ***Use TAI*** toggle boxes for the top two materials. Both of these layers are asphalt concrete and must be analyzed using the TAI equation.

Step 3. Perform the analysis and print the results. Click on the ***Analyze*** button at the top of the screen. After the analysis is completed and the results screen appears, as in Screen Clip 4-28, use your mouse to point and click on the ***Print*** button at the top of the output screen.

Step 4. Interpret the results. All of the AKFPD output is contained on the output screen, as shown in Screen Clip 4-28. Example 1 identifies and generally explains the contents of each section and column of this screen. You should also have a printed copy of the output to follow along with the following interpretation.



Alaska Flexible Pavement Design 2003 Mechanistic Design Method - [OVERLAY DESIGN Analysis Results for: Example_02 @ 9:45:58 AM]

View Window Print

Project: Example_02
Proj No.: AK-1224-RD(07)

Overlay Design by:Billy Bob McConnor
6/27/03 9:45:57 AM

AADT = 2,500	Past Loadings	Future Loadings						X/Y Load Locations (in): Load = 4500 (lbs) Tire Pressure = 80 (psi)		0 0	13.5 0
10% Spring 40% Summer 10% Fall 40% Winter --------------- Total:	30,000 120,000 30,000 120,000 ---------- 300,000	125,000 500,000 125,000 500,000 ---------- 1,250,000							X/Y Evaluation Points (in):	6.75 0	0 0
Layer	Critical Z Coordinate	Asphalt Properties	Season	Modulus (ksi)	Poisson's Ratio	Tensile Critical Micro Strain	Critical Compressive Stress (psi)	Million Cycles to Failure	Past Damage %	Future Damage %	Total Damage %
2(in) New_Asphalt Overlay	1.99	5% Air 6% Asph 149 pcf	Spring	350	0.35	16.7		13,403.32		0.00	0.00%
			Summer	350	0.35	32.3		1,528.93	0.00	0.03	0.03%
			Fall	350	0.35	32.3		1,528.93	0.00	0.01	0.01%
			Winter	1,500	0.35	13.7		7,421.25	0.00	0.01	0.01%
								Total Damage:	0.00	0.05	0.05
3(in) Asphalt	4.99	2% Air 6.5% Asph 155 pcf	Spring	350	0.35	220		14.64	0.93	0.85	1.78%
			Summer	500	0.35	174		23.36	1.65	2.14	3.79%
			Fall	500	0.35	174		23.36	0.41	0.54	0.95%
			Winter	1,500	0.35	80.8		114.11	0.47	0.44	0.90%
								Total Damage:	3.45	3.97	7.42
6(in) Crushed Agg Base Course	5.01		Spring	20	0.4		21.60	0.28	0.00	43.99	43.99%
			Summer	35	0.4		20.70	2.19	0.00	22.87	22.87%
			Fall	35	0.4		20.70	2.19	0.00	5.72	5.72%
			Winter	50	0.4		13.20	30.32	0.00	1.65	1.65%
								Total Damage:	0.00	74.22	74.22
24(in) Subbase	11.01		Spring	500	0.4		16.90	24,655.00		0.00	0.00%
			Summer	50	0.4		12.00	41.37	0.00	1.21	1.21%
			Fall	50	0.4		12.00	41.37	0.00	0.30	0.30%
			Winter	50	0.4		7.92	160.31	0.00	0.31	0.31%
								Total Damage:	0.00	1.82	1.82
36(in) Subgrade on FF Rigid Layer	35.01		Spring	60	0.4		1.95	28,017.77		0.00	0.00%
			Summer	6	0.4		1.38	23.47	0.00	2.13	2.13%
			Fall	6	0.4		1.38	23.47	0.00	0.53	0.53%
			Winter	6	0.4		1.19	38.05	0.00	1.31	1.31%
								Total Damage:	0.00	3.98	3.98

Screen Clip 4-28

To interpret the results of this overlay design example, examine the three columns at the right side of the output. The column labeled ***Past Damage %*** lists the percent of structural life expended, for each layer and season, due to past traffic (ESALs applied prior to the overlay). The column labeled ***Future Damage %*** lists the percent structural life expended, for each layer and season, due to future traffic (design ESALs). Each line of the column labeled ***Total Damage %*** contains the sum of the other two columns (see further discussion of this sum in item "a" below). The last column, ***Total Damage %,*** is the principal one for interpreting this design analysis.

In the ***Total Damage %*** column, notice that the summation of seasonal damage for each material type (examine printout or screen to see sums listed in blue) is less than 100%. This shows that the structural life of none of the material layers has been exceeded in AKFPD's final design. At this point, stop and appreciate the fact that the AKFPD program has completed many steps of the overlay design process automatically—and it has saved you a *lot* of work. The automatic overlay design process is an iterative but simple one. AKFPD iterates through increasing thicknesses of overlay pavement until the final overlay thickness is enough to satisfy the structural requirements of past plus future ESALs. AKFPD knows when to stop the iterative process when the overlay thickness is great enough that summations in the ***Total Damage %*** column are all less than 100%.

Now examine the final overlay thickness (2 inches) listed at the top of the left column of your output screen or Screen Clip 4-28 labeled ***Layer.*** Assuming that other factors (factors not considered by the AKFPD program) do not require additional consideration, you may recommend an overlay design thickness of 2 inches.

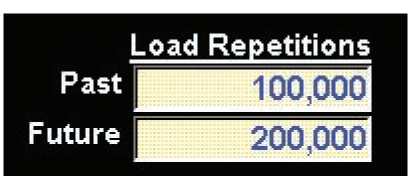
Although the main point of an overlay analysis is to determine the overlay thickness, you should consider a few additional points:

a. The overlay asphalt concrete pavement receives 0.05% damage only from future ESALs.

b. For asphalt concrete layers exposed to past ESALs and future design ESALs, the AKFPD program adds the percentage of structural life consumed by both past and future ESALs. This sum, 7.42%, is shown for the original 3-inch asphalt concrete layer. The sum includes 3.45% damage from past ESALs plus 3.97% damage from future ESALs. The TAI equation is used to calculate percent damage for these bound materials. For bound materials, past damage is added to future design ESAL damage because percent structural damage in bound materials is cumulative during the entire time those materials remain in the pavement structure. Miner's law accumulates damage for ESALs applied both before and after the overlay.

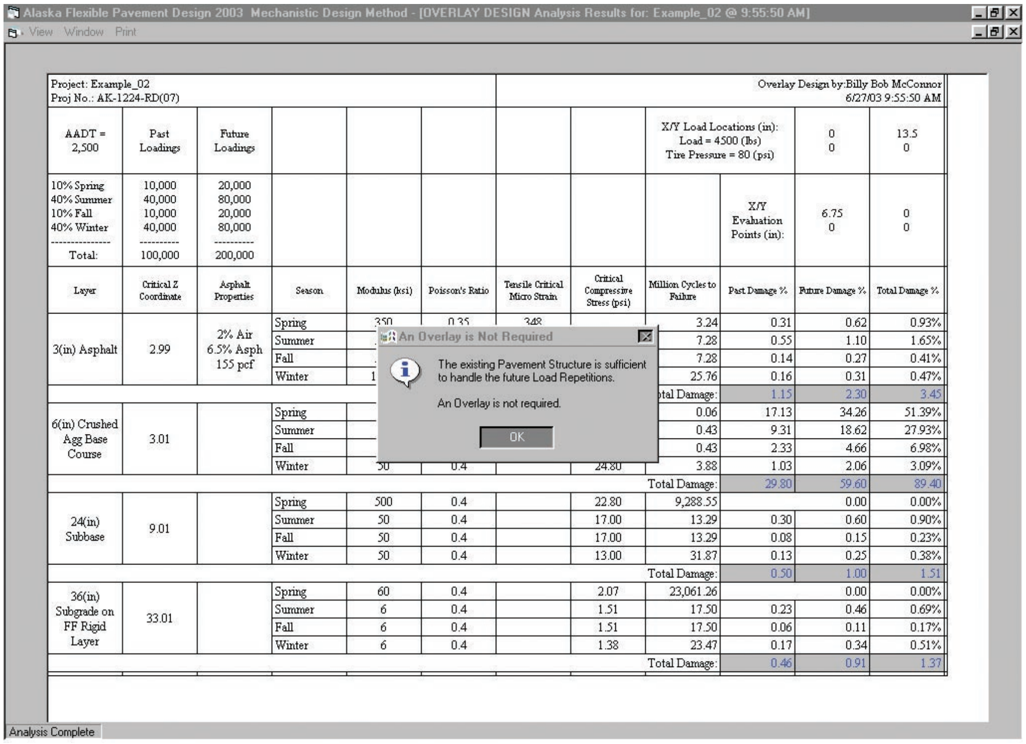
c. Soil and aggregate layers containing less than 4% asphalt cement are considered to be unbound materials and AKFPD uses the Per Ullidtz equation to calculate percent damage. For those materials, the ***Past Damage %*** column is re-zeroed when AKFPD begins to add overlay thickness (as in this example). Examine the ***Past Damage %*** column on your printout or the output screen and observe that any structural damage percentage accumulated because past ESALs have been set to zero. The Miner's law damage accumulation is reset by overlay repair work because, for unbound materials, the overlay process completely repairs roughness and rutting damage accumulated prior to the overlay.

d. If AKFPD determines that no overlay is required to handle past plus future ESALs (not the case in this example), a note will appear on the output screen. You can easily test this by returning to your input screen and replacing this example's ESAL data with the values in Screen Clip 4-29.



Screen Clip 4-29

Now click on the ***Analyze*** button at the top of the input screen. The output screen shown as Screen Clip 4-30 will appear when the analysis is complete.



Project: Example_02 Proj No.: AK-1224-RD(07)										Overlay Design by:Billy Bob McConnor 6/27/03 9:55:50 AM		
AADT = 2,500	Past Loadings	Future Loadings						X/Y Load Locations (in): Load = 4500 (lbs) Tire Pressure = 80 (psi)			0 0	13.5 0
10% Spring 40% Summer 10% Fall 40% Winter Total:	10,000 40,000 10,000 40,000 100,000	20,000 80,000 20,000 80,000 200,000							X/Y Evaluation Points (in):	6.75 0	0 0	
Layer	Critical Z Coordinate	Asphalt Properties	Season	Modulus (ksi)	Poisson's Ratio	Tensile Critical Micro Strain	Critical Compressive Stress (psi)	Million Cycles to Failure	Past Damage %	Future Damage %	Total Damage %	
3(in) Asphalt	2.99	2% Air 6.5% Asph 155 pcf	Spring	350	0.35	348		3.24	0.31	0.62	0.93%	
			Summer					7.28	0.55	1.10	1.65%	
			Fall					7.28	0.14	0.27	0.41%	
			Winter	1				25.76	0.16	0.31	0.47%	
								tal Damage:	1.15	2.30	3.45	
6(in) Crushed Agg Base Course	3.01		Spring					0.06	17.13	34.26	51.39%	
			Summer					0.43	9.31	18.62	27.93%	
			Fall					0.43	2.33	4.66	6.98%	
			Winter	50	0.4		24.80	3.88	1.03	2.06	3.09%	
								Total Damage:	29.80	59.60	89.40	
24(in) Subbase	9.01		Spring	500	0.4		22.80	9,288.55		0.00	0.00%	
			Summer	50	0.4		17.00	13.29	0.30	0.60	0.90%	
			Fall	50	0.4		17.00	13.29	0.08	0.15	0.23%	
			Winter	50	0.4		13.00	31.87	0.13	0.25	0.38%	
								Total Damage:	0.50	1.00	1.51	
36(in) Subgrade on FF Rigid Layer	33.01		Spring	60	0.4		2.07	23,061.26		0.00	0.00%	
			Summer	6	0.4		1.51	17.50	0.23	0.46	0.69%	
			Fall	6	0.4		1.51	17.50	0.06	0.11	0.17%	
			Winter	6	0.4		1.38	23.47	0.17	0.34	0.51%	
								Total Damage:	0.46	0.91	1.37	

Screen Clip 4-30

You can examine the new output screen to see that: (1) no overlay was needed, and (2) the ***Past Damage %*** column has not been zeroed before future ESALs are applied. Note that damage due to past and future design ESALs for the aggregate base course are 29.8% and 59.6% respectively, for a total of 89.4%.

- Review the interpretation described for example 1 (step 16 of that analysis) as a guide for wringing additional information from the output screen.

4.6.5 Example 3—A Stabilized Base Design

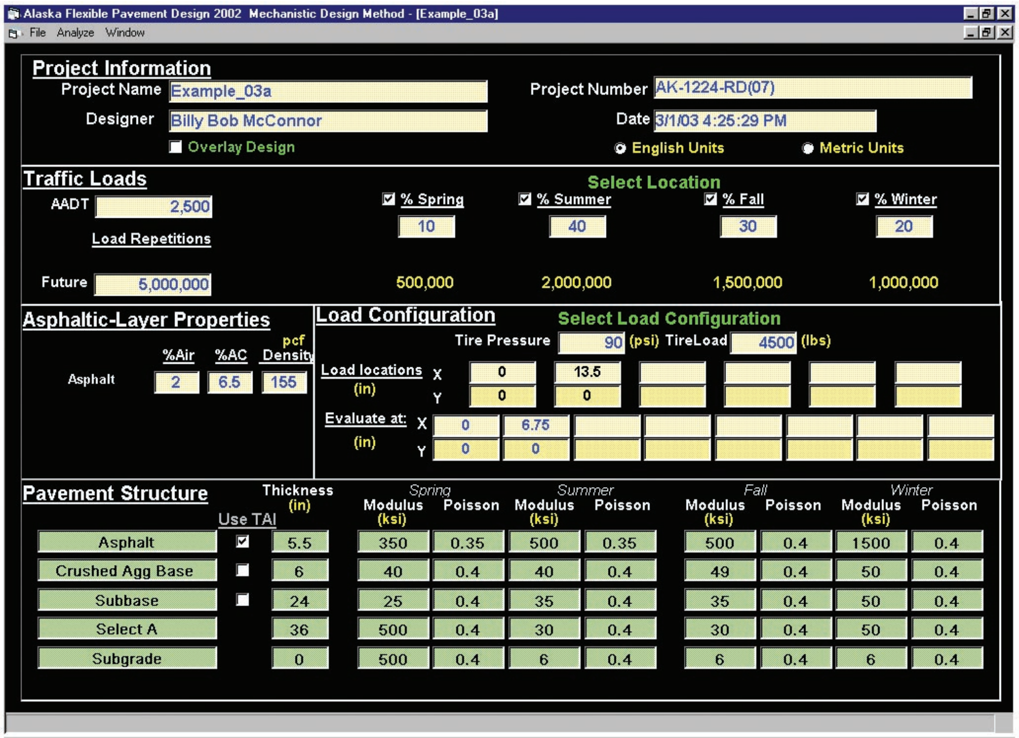
This example examines the use of stabilized base courses. Stabilized bases are now prescribed, by policy, for inclusion in most DOT&PF pavement designs. All else being equal, properly done base course stabilization does improve the ESAL capacity of any pavement structure. The stabilized base policy indirectly considers and compensates for unforeseen variables such as materials problems, construction-related problems, and future vehicle loadings that may exceed design ESALs.

A stabilized base course usually has a significantly more structural stiffness (higher M_R value) than a non-stabilized material. In Alaska, base stabilization is most often achieved by adding a bonding agent—usually asphalt cement—to an available base course material. Lately, mixtures of crushed, recycled asphalt pavement (RAP), with and without the addition of extra asphalt cement binder, have been used to satisfy the stabilized base policy. Life-cycle cost considerations not withstanding, it is your responsibility to comply with this policy to the extent possible.

You will gain cumulative experience in going through each design example in turn because each successive example builds on information and tips contained in the previous one. This example uses many of the program operation techniques presented in Section 4.6.2, example 1. **If you have not thoroughly familiarized yourself with example 1, do so before proceeding with this example.**

This example will compare the results of three analyses. In the first analysis you will determine the pavement thickness requirement of a pavement structure that contains a normal crushed aggregate base course. In the next analysis you will determine the pavement thickness required if the normal crushed aggregate base is replaced with the same thickness of lightly stabilized base course. In the third analysis you will determine the pavement thickness if a heavily stabilized base course is used.

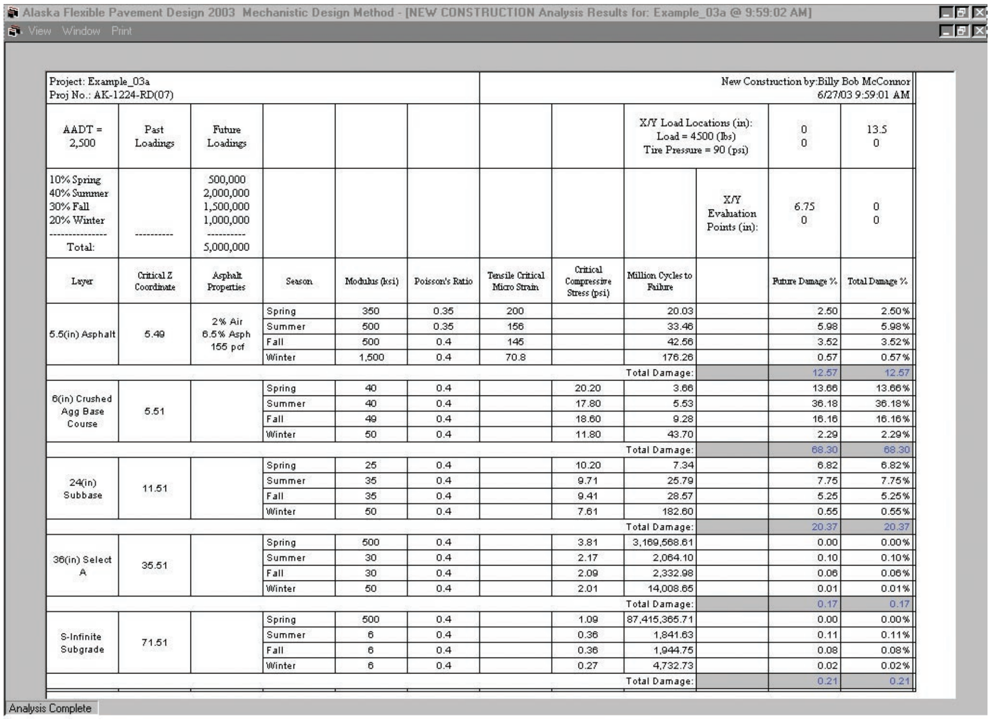
Step 1. Begin this example by initiating the ***Mechanistic Design Method, New Analysis*** input screen. Using mouse and keyboard, enter data for the example until the input screen is as shown in Screen Clip 4-31.



Screen Clip 4-31

Step 2. Analyze, then print the results. Click on the Analyze button at the top of the input screen. After the results screen is displayed, click on the ***Print*** button at the top of the output screen shown as Screen Clip 4-32.

Step 3. Interpret the results. As you can see, the analysis requires 5.5 inches of asphalt concrete pavement over a crushed aggregate base course to handle the 5-million ESAL design load. Identify this thickness by analyzing increasing thicknesses of pavement until the seasonal damage sums for all of the material layers (see right column of Screen Clip 4-32) are less than 100%. You should now try pavement thicknesses less than 5.5 inches to verify that 5.5 inches are really required (see for yourself that 5 inches *almost* works).



Alaska Flexible Pavement Design 2003 Mechanistic Design Method - [NEW CONSTRUCTION Analysis Results for: Example_03a @ 9:59:02 AM]

View Window Print

Project: Example_03a
Proj No.: AK-1224-RD(07)

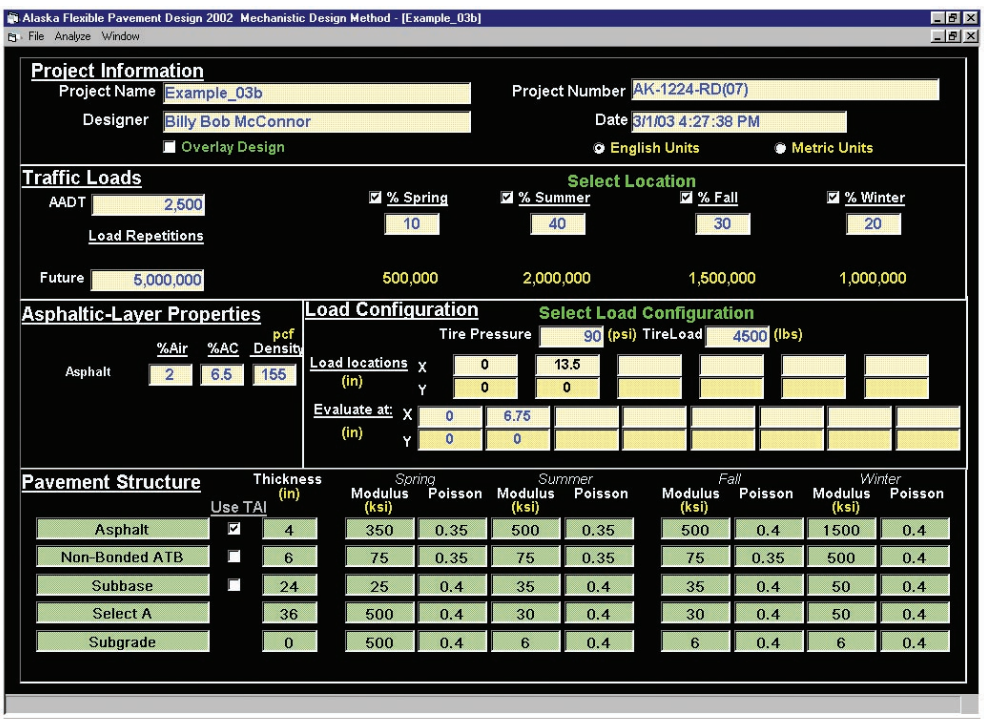
New Construction by:Billy Bob McConnor
6/27/03 9:59:01 AM

AADT = 2,500	Past Loadings	Future Loadings						X/Y Load Locations (in): Load = 4500 (lbs) Tire Pressure = 90 (psi)		0 0	13.5 0
10% Spring 40% Summer 30% Fall 20% Winter --------------- Total:	----------	500,000 2,000,000 1,500,000 1,000,000 ---------- 5,000,000							X/Y Evaluation Points (in):	6.75 0	0 0
Layer	Critical Z Coordinate	Asphalt Properties	Season	Modulus (ksi)	Poisson's Ratio	Tensile Critical Micro Strain	Critical Compressive Stress (psi)	Million Cycles to Failure		Future Damage %	Total Damage %
5.5(in) Asphalt	5.49	2% Air 6.5% Asph 155 pcf	Spring	350	0.35	200		20.03		2.50	2.50%
			Summer	500	0.35	156		33.46		5.98	5.98%
			Fall	500	0.4	145		42.56		3.52	3.52%
			Winter	1,500	0.4	70.8		176.26		0.57	0.57%
								Total Damage:		12.57	12.57
6(in) Crushed Agg Base Course	5.51		Spring	40	0.4		20.20	3.66		13.66	13.66%
			Summer	40	0.4		17.80	5.53		36.18	36.18%
			Fall	49	0.4		18.60	9.28		16.16	16.16%
			Winter	50	0.4		11.80	43.70		2.29	2.29%
								Total Damage:		68.30	68.30
24(in) Subbase	11.51		Spring	25	0.4		10.20	7.34		6.82	6.82%
			Summer	35	0.4		9.71	25.79		7.75	7.75%
			Fall	35	0.4		9.41	28.57		5.25	5.25%
			Winter	50	0.4		7.61	182.60		0.55	0.55%
								Total Damage:		20.37	20.37
36(in) Select A	35.51		Spring	500	0.4		3.81	3,169,568.61		0.00	0.00%
			Summer	30	0.4		2.17	2,064.10		0.10	0.10%
			Fall	30	0.4		2.09	2,332.98		0.06	0.06%
			Winter	50	0.4		2.01	14,008.65		0.01	0.01%
								Total Damage:		0.17	0.17
S-Infinite Subgrade	71.51		Spring	500	0.4		1.09	87,415,365.71		0.00	0.00%
			Summer	6	0.4		0.36	1,841.63		0.11	0.11%
			Fall	6	0.4		0.36	1,944.75		0.08	0.08%
			Winter	6	0.4		0.27	4,732.73		0.02	0.02%
								Total Damage:		0.21	0.21

Analysis Complete

Screen Clip 4-32

Step 4. Now analyze use of a lightly stabilized base course. Set up an input screen for this analysis by modifying the previous input screen to substitute new base course materials properties as shown in Screen Clip 4-33.



Screen Clip 4-33

Notice that the only changes to the base course properties involve raising the M_R values to 75 ksi, 75 ksi, 75 ksi, and 500 ksi for spring, summer, fall, and winter respectively.

Step 5. Perform the analysis and print the results.

Step 6. Interpret the results. The pavement thickness requirement is substantially reduced from that needed with normal base course (see Screen Clip 4-34). The lightly stabilized base requires only 4 inches of asphalt concrete pavement over the stabilized base to handle the 5-million ESAL design load. By using the lightly stabilized base (≈ 3% emulsion added to a crushed granular base), you have saved 1.5 inches of hot mix asphalt concrete pavement.

Alaska Flexible Pavement Design 2003 Mechanistic Design Method - [NEW CONSTRUCTION Analysis Results for: Example_03b @ 10:15:48 AM]

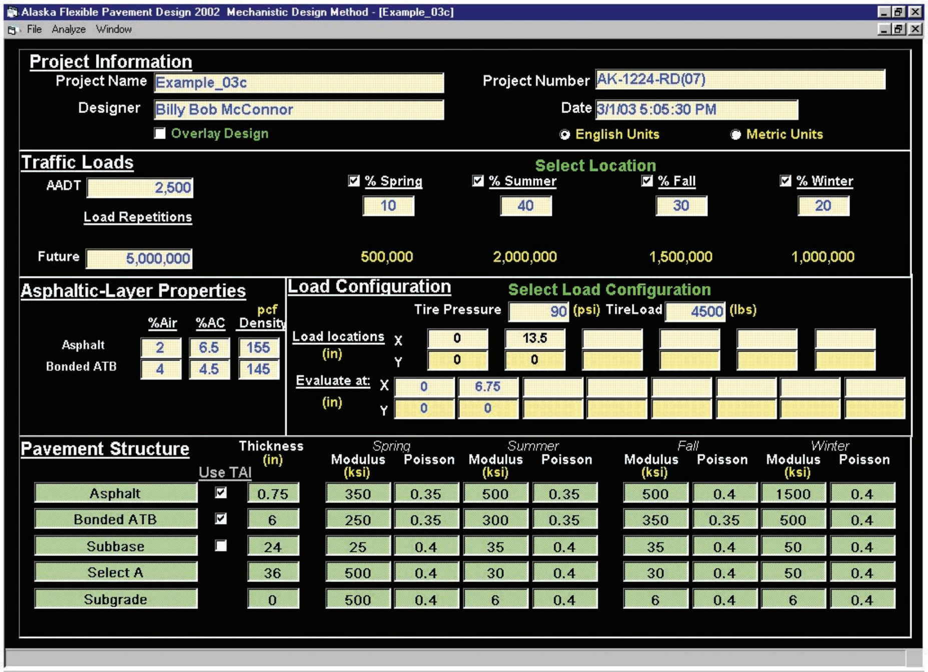
View Window Print

Project: Example_03b Proj No.: AK-1224-RD(07)						New Construction by:Billy Bob McConnor 6/27/03 10:15:47 AM					
AADT = 2,500	Past Loadings	Future Loadings						X/Y Load Locations (in): Load = 4500 (lbs) Tire Pressure = 90 (psi)		0 0	13.5 0
10% Spring 40% Summer 30% Fall 20% Winter --------------- Total:	----------	500,000 2,000,000 1,500,000 1,000,000 ---------- 5,000,000							X/Y Evaluation Points (in):	6.75 0	0 0
Layer	Critical Z Coordinate	Asphalt Properties	Season	Modulus (ksi)	Poisson's Ratio	Tensile Critical Micro Strain	Critical Compressive Stress (psi)	Million Cycles to Failure		Future Damage %	Total Damage %
4(in) Asphalt	3.99	2% Air 6.5% Asph 155 pcf	Spring	350	0.35	184		26.35		1.90	1.90%
			Summer	500	0.35	154		34.91		5.73	5.73%
			Fall	500	0.4	154		34.91		4.30	4.30%
			Winter	1,500	0.4	32.2		2,356.52		0.04	0.04%
								Total Damage:		11.97	11.97
6(in) Non-Bonded ATB	4.01		Spring	75	0.35		36.40	4.17		12.00	12.00%
			Summer	75	0.35		32.40	6.09		32.85	32.85%
			Fall	75	0.35		31.90	6.40		23.42	23.42%
			Winter	500	0.4		39.50	1,548.49		0.06	0.06%
								Total Damage:		68.34	68.34
24(in) Subbase	10.01		Spring	25	0.4		11.50	4.96		10.08	10.08%
			Summer	35	0.4		11.50	14.86		13.46	13.46%
			Fall	35	0.4		11.40	15.29		9.81	9.81%
			Winter	50	0.4		6.72	273.90		0.37	0.37%
								Total Damage:		33.72	33.72
36(in) Select A	34.01		Spring	500	0.4		4.02	2,660,961.83		0.00	0.00%
			Summer	30	0.4		2.28	1,756.79		0.11	0.11%
			Fall	30	0.4		2.26	1,807.99		0.08	0.08%
			Winter	50	0.4		1.73	22,844.69		0.00	0.00%
								Total Damage:		0.20	0.20
S-Infinite Subgrade	70.01		Spring	500	0.4		1.13	66,640,228.42		0.00	0.00%
			Summer	6	0.4		0.37	1,685.08		0.12	0.12%
			Fall	6	0.4		0.37	1,714.96		0.09	0.09%
			Winter	6	0.4		0.26	5,417.25		0.02	0.02%
								Total Damage:		0.22	0.22

Analysis Complete

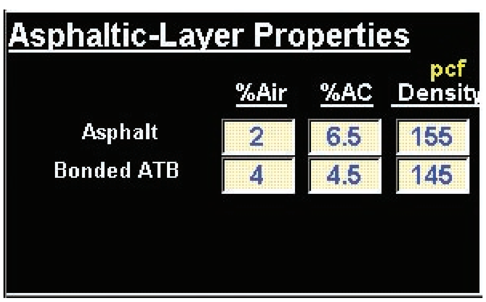
Screen Clip 4-34

Step 7. Finally, analyze using a heavily stabilized base course (>4% asphalt cement added to a crushed granular base). Set up an input screen for this analysis, as shown in Screen Clip 4-35, by first increasing the base course moduli to 250 ksi, 300 ksi, 350 ksi, and 500 ksi for spring, summer, fall, and winter respectively.



Screen Clip 4-35

An additional change is also required on the input screen. Notice that the ***Use TAI*** toggle boxes in Screen Clip 4-35 now contain two checkmarks. The lower checkmark means that the heavily stabilized base will contain enough asphalt cement that the layer will require TAI analysis as a fully bound layer. The base course will be analyzed by assessing the tensile strain at the bottom of the layer. Because the second ***Use TAI*** toggle box is checked, you must also enter a second line of input values, as shown in Screen Clip 4-36, in the ***Asphaltic-Layer Properties*** section of the input screen, i.e., ***%Air*** = 4, ***%AC*** = 4.5, and ***pcf Density*** = 145.



Screen Clip 4-36

Step 8. Perform the analysis and print the results.

Step 9. Interpret the results. The pavement thickness requirement has now been drastically reduced from the 5.5 inches needed with normal base course (see output in Screen Clip 4-37). The heavily stabilized base requires only 0.75 inches of asphalt concrete pavement over the stabilized base to handle the 5-million ESAL design load! According to the mechanistic design method, you can do away with most of the pavement. The implication here is that an asphalt surface treatment, such as a double-layer AST or a high float AST, will be sufficient.

So, only 0.75 inches of pavement is theoretically required for a rather huge design loading of 5 million ESALs. However, other factors come into play in considering the final pavement thickness, not addressed in the mechanistic design. For example, a thin pavement may abrade away quickly from studded tire wear. Also, thin pavements contain small aggregates that may offer little resistance to rutting caused by simple plastic deformation. For these and other reasons, and considering the enormous ESALs, a minimum thickness of perhaps

2 inches or more may be necessary. Such considerations strongly suggest that you share the responsibility of your final design recommendations with your friendly pavement design experts located in regional and/or headquarters Materials sections.

As with all designs where there are several options, a cost analysis should be an important part of your decision.

Alaska Flexible Pavement Design 2003 Mechanistic Design Method - [NEW CONSTRUCTION Analysis Results for: Example_03c @ 10:18:28 AM]

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Project: Example_03c
Proj No.: AK-1224-RD(07)

New Construction by:Billy Bob McConnor
6/27/03 10:18:28 AM

AADT = 2,500	Past Loadings	Future Loadings						X/Y Load Locations (in): Load = 4500 (lbs) Tire Pressure = 90 (psi)		0 0	13.5 0
10% Spring 40% Summer 30% Fall 20% Winter --------------- Total:	----------	500,000 2,000,000 1,500,000 1,000,000 ---------- 5,000,000							X/Y Evaluation Points (in):	6.75 0	0 0
Layer	**Critical Z Coordinate**	**Asphalt Properties**	**Season**	**Modulus (ksi)**	**Poisson's Ratio**	**Tensile Critical Micro Strain**	**Critical Compressive Stress (psi)**	**Million Cycles to Failure**		**Future Damage %**	**Total Damage %**
0.75(in) Asphalt	0.74	2% Air 6.5% Asph 155 pcf	Spring	350	0.35	85.4		329.57		0.15	0.15%
			Summer	500	0.35	79.1		312.74		0.64	0.64%
			Fall	500	0.4	94.7		172.95		0.87	0.87%
			Winter	1,500	0.4	50.6		532.43		0.19	0.19%
								Total Damage:		1.85	1.85
6(in) Bonded ATB	6.74	4% Air 4.5% Asph 145 pcf	Spring	250	0.35	218		3.11		16.08	16.08%
			Summer	300	0.35	168		6.27		31.89	31.89%
			Fall	350	0.35	154		7.32		20.49	20.49%
			Winter	500	0.4	104		19.65		5.09	5.09%
								Total Damage:		73.54	73.54
24(in) Subbase	6.76		Spring	25	0.4		15.30	1.96		25.56	25.56%
			Summer	35	0.4		15.70	5.39		37.14	37.14%
			Fall	35	0.4		14.60	6.82		21.98	21.98%
			Winter	50	0.4		13.70	26.86		3.72	3.72%
								Total Damage:		88.41	88.41
36(in) Select A	30.76		Spring	500	0.4		4.80	1,492,688.35		0.00	0.00%
			Summer	30	0.4		2.76	942.38		0.21	0.21%
			Fall	30	0.4		2.70	1,012.38		0.15	0.15%
			Winter	50	0.4		2.63	5,831.23		0.02	0.02%
								Total Damage:		0.38	0.38
S-Infinite Subgrade	66.76		Spring	500	0.4		1.25	19,919,258.81		0.00	0.00%
			Summer	6	0.4		0.42	1,170.44		0.17	0.17%
			Fall	6	0.4		0.41	1,217.50		0.12	0.12%
			Winter	6	0.4		0.32	2,838.82		0.04	0.04%
								Total Damage:		0.33	0.33

Analysis Complete

Screen Clip 4-37